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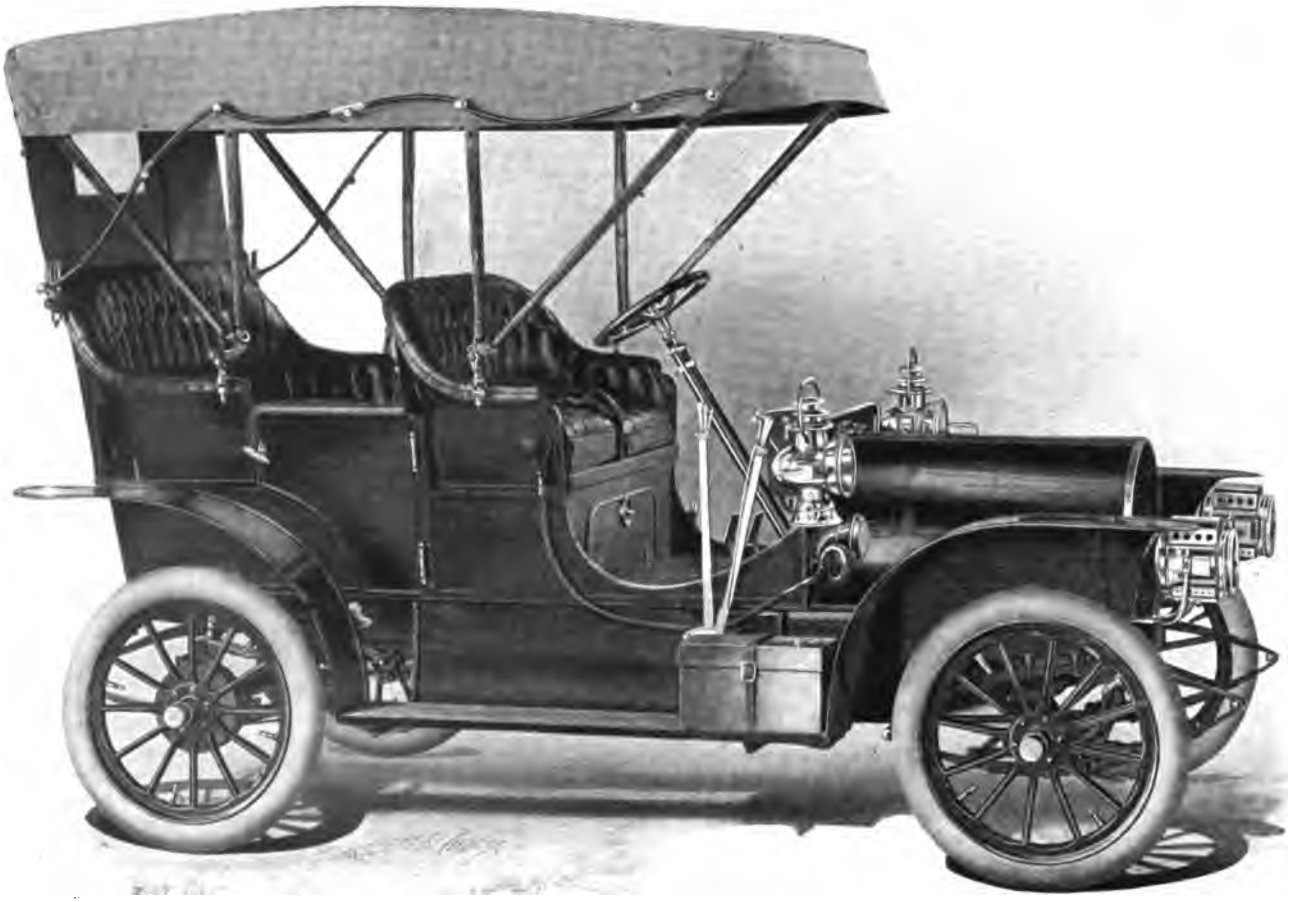

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Grateful acknowledgment is here made also for the invaluable co-operation of the foremost manufacturers and engineering firms, in making these volumes thoroughly representative of the best and latest practice in the design and construction of steam and gas engines, machine tools, and other classes of modern machinery; also for the valuable drawings and data, suggestions, criticisms, and other courtesies.

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Foreword

THE rapid advances made in recent years in the field of Mechanical Engineering, as seen in the evolution of improved types of machinery, new mechanical processes and methods, and even new materials of workmanship, have created a distinct necessity for an authoritative work of general reference embodying the accumulated results of modern experience and the latest approved practice. The Cyclopedia of Mechanical Engineering is designed to fill this acknowledged need.

¶ The aim of the publishers has been to create a work which, while adequate to meet all demands of the technically trained expert, will appeal equally to the self-taught practical man, who, as a result of the unavoidable conditions of his environment, may be denied the advantages of training at a resident technical school. The Cyclopedia not only covers the fundamentals that underlie all mechanical engineering, but places the reader in direct contact with the experience of teachers fresh from practical work, thus putting him abreast of the latest progress and furnishing him that adjustment to advanced modern needs and conditions which is a necessity even to the technical graduate.

¶ The Cyclopedia of Mechanical Engineering is based upon the method which the American School of Correspondence has developed and successfully used for many years in teaching the principles and practice of engineering in its different branches. It is a compilation of representative Instruction Books of the

School, and forms a simple, practical, concise, and convenient reference work for the shop, the library, the school, and the home.

¶ The success which the American School of Correspondence has attained as a factor in the machinery of modern technical and scientific education, is in itself the best possible guarantee for the present work. Therefore, while these volumes are a marked innovation in technical literature—representing, as they do, the best ideas and methods of a large number of *different* authors, each an acknowledged authority in his work—they are by no means an experiment, but are in fact based on what has proved itself to be the most successful method yet devised for the education of the busy workingman. They have been prepared only after the most careful study of modern needs as developed under the conditions of actual practice in the Machine Shop, the Engine Room, the Drafting Room, the Factory, etc. The formulæ of the higher mathematics have been avoided as far as possible, and every care exercised to elucidate the text by abundant and appropriate illustrations.

¶ Numerous examples for practice are inserted at intervals; these, with the test questions, help the reader to fix in mind the essential points, thus combining the advantages of a text-book with those of a reference work.

¶ Grateful acknowledgment is due the corps of editors and authors—engineers and designers of wide practical experience, and teachers of well-recognized ability—without whose co-operation this work would have been impossible.

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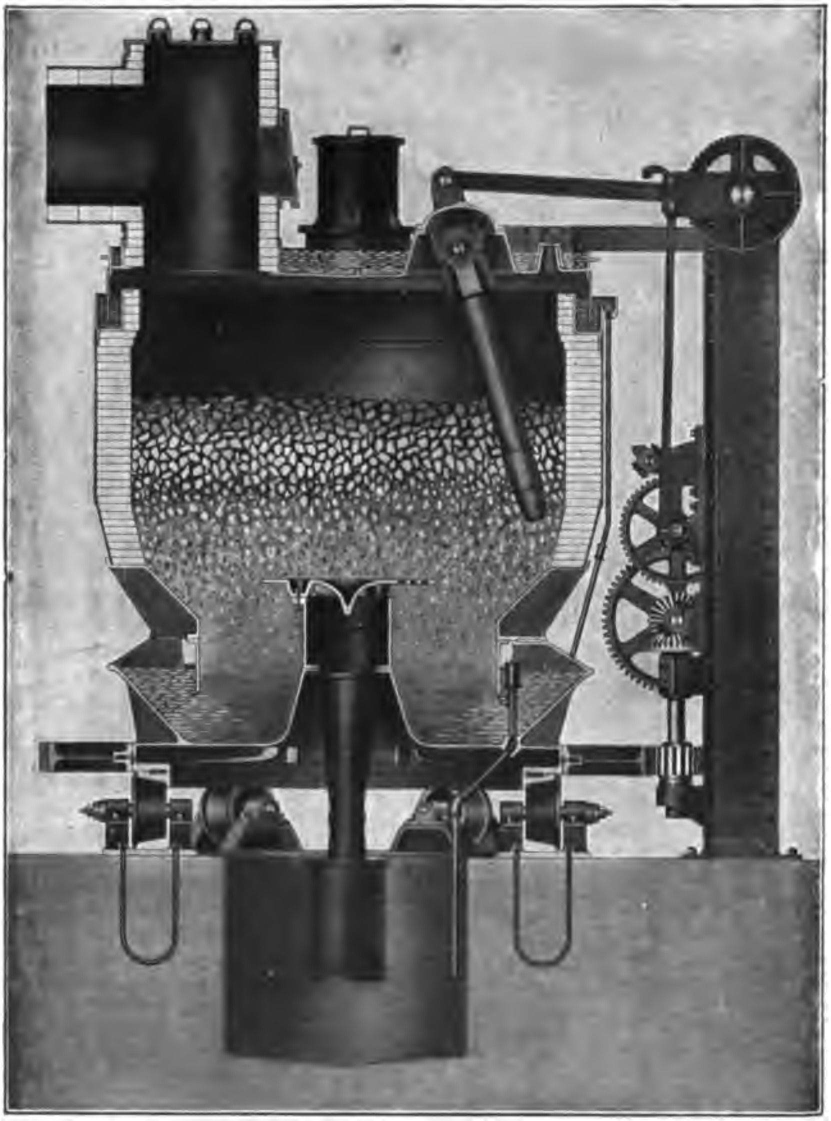


SECTIONAL VIEW OF HUGHES PATENT MECHANICALLY-POKED CONTINUOUS GAS PRODUCER

Standard Size is 10 ft. Diameter Inside of Fire Brick Lining, and 11 ft. 6 in. Outside of Shell

GAS-PRODUCERS

INTRODUCTION

Gaseous fuel has long been a desideratum, and many modern industries demand it for their successful operation. Where nature has not supplied it, man has been compelled to make it. The intelligent appreciation of the method of manufacture and of the advantages of gaseous fuels in general, and producer gas in particular, necessitates a clear understanding of certain fundamental facts.

Gases may be divided into three classes: *Elementary*, *Compound*, and *Mixtures*. Elementary gases consist of one element only—as oxygen, for instance. Compound gases are composed of two or more elements in chemical combination—as marsh gas, for instance, in which carbon and hydrogen are combined. Mixtures are not definite compounds, but consist of two or more elementary or compound gases simply mixed together without any chemical affinity existing between any of the constituents. Producer gas belongs to the class of mixtures. Table 1 shows the composition of a representative sample of producer gas:

TABLE I

Typical Producer-Gas Analysis

Combustible .	Hydrogen	8.0	per cent
	Marsh gas	3.0	" "
	Olefiant gas	0.5	" "
	Carbon monoxide	24.0	" "
Condensible. .	Tar	1.0	" "
	Water vapor	1.0	" "
Diluents.	Carbon dioxide	3.0	" "
	Oxygen	0.5	" "
	Nitrogen	59.0	" "
		100.0	

The proportion of each constituent present will depend upon the nature of the raw fuel, the type of producer, and the method of operation. Water vapor and tar, although generally present, are not usually determined and given in the analysis, since both will nearly always condense within a short distance from the producer. It is evident that the properties of producer gas will be determined by its constituents. That is, the presence of certain desirable or undesirable constituents will give the gas desirable or undesirable properties, and these properties will be proportional to the relative percentage present of the constituents in question. Hence it is desirable to know the properties of each constituent so that its effect on the gas as a whole may be determined.

Hydrogen is the lightest known substance, is colorless, odorless, non-poisonous, very combustible, non-luminous, and burns with a pale blue flame.

Marsh gas, also called methane, is odorless, colorless, has a high calorific power but slow rate of combustion, and burns with a slightly luminous flame.

Olefiant gas, also called ethylene or ethene, has a high calorific power, is colorless and odorless, and burns with a very luminous flame. It is sometimes spoken of as an "illuminant."

Carbon monoxide, also called carbonic oxide, is a deadly poison, colorless, odorless, insoluble in water, and burns with a blue flame.

Carbon dioxide, also called carbonic anhydride or carbonic acid, is soluble in water, odorless, colorless, and non-combustible.

Oxygen is colorless, tasteless, odorless, and its presence in producer gas decreases the amount of oxygen that must be furnished for combustion.

Nitrogen is odorless, colorless, non-combustible, and has no effect on producer gas except to act as a diluent.

Water vapor comes from undecomposed steam passing through the fuel. On account of its high specific heat, it may cause a large heat loss.

The tar in producer gas comes directly from the fuel; it will condense quite easily and will then be precipitated in the pipes.

A fixed or permanent gas is one that will not precipitate any condensible constituents when the gas is cooled. Producer gas should be composed of fixed gases only. The gas will always be cooled after leaving the producer; and, if it contains any condensible constituents, these will be deposited in the pipes; not only will this cause a heat loss but will also give trouble from the clogging of the pipes.

The volume of a gas varies with the temperature and pressure. In order to secure comparable results from different analyses, it is necessary that some definite standard be used. This is known as the *standard condition,* and is taken as 32 degrees Fahrenheit and a pressure of 29.92 inches of mercury—or its metric equivalent, 0 degrees Centigrade and a pressure of 760 millimeters of mercury.

The *specific gravity* of a gas is the ratio of the weight of a unit volume of the gas to the weight of a unit volume of another gas taken as a standard, and at the same standard condition. Hydrogen and air are the standards usually used. With reference to air, the specific gravity of producer gas is about .86.

The *thermal capacity* of a substance is the heat required to raise the temperature of a unit weight of it one degree. The *specific heat* of a gas is the ratio between the thermal capacities of equal weights of the gas and water.

The *sensible heat* of a gas is the heat that it carries by virtue of its temperature. It is equal to the product of the volume of gas and its specific heat per unit of volume.

TABLE II

Combustion Data

	NAME	SYMBOL	ATOMIC WEIGHT	SPECIFIC HEAT PER CU. FOOT	SPECIFIC GRAVITY AIR = 1	WEIGHT PER CU. FOOT IN POUNDS	B. T. U. EVOLVED PER CU. FOOT	COMBUSTION PRODUCT
COMBUSTIBLE GASES	Hydrogen ...	H	1	.0194	.069	.0056	346	$H + 20 = H_2O$
	Marsh gas...	CH_4		.0264	.559	.045	1070	$CH_4 + 40 = CO_2 + 2H_2O$
	Olefiant gas..	C_2H_4		.0289	.967	.078	1670	$C_2H_4 + 60 = 2CO_2 + 2H_2O$
	Carbon monoxide..	CO		.0193	.967	.078	342	$CO + O = CO_2$
DILUENT GASES	Carbon dioxide ...	CO_2		.0265	1.529	.123		
	Oxygen	O	16	.0194	1.105	.089		
	Nitrogen	N	14	.0192	.972	.078		
	Water vapor at 212° F..	H_2O		.0173	.469	.036		
	Carbon	C	12	1 lb. evolves 4,450 B. T. U. when burned to CO				
	Carbon	C	12	1 " " 14,500 " " " " CO_2				

The *British thermal unit* (B. T. U.) is the amount of heat required to raise one pound of water one degree Fahrenheit. The Centigrade unit (C. U.) is the amount of heat required to raise one pound of water one degree Centigrade.

The calory is the amount of heat required to raise one kilogram of water one degree Centigrade.

The *gram-calory* is the amount of heat required to raise one gram of water one degree Centigrade.

The *calorific power*—or, which is the same thing, the *heating power*—of a gas, is the number of heat units evolved by the complete combustion of a unit volume of the gas.

Gas firing requires that the fuel bed be *thick* and *compact* enough to permit only a partial combustion of the fuel, so that a stream of combustible gas will be given off at the surface of the fuel. Direct firing requires that the fuel bed shall be sufficiently *thin* and *porous* to permit enough oxygen to get through the interstices in the fuel bed to produce vigorous combustion at the surface of the fuel.

GASEOUS FUELS

A proper understanding of producer gas requires a clear conception of the other well-known gaseous fuels with which it is frequently associated.

Retort gas is made by the destructive distillation of coal—*i. e.*, by heating coal in retorts without access of air. The gases are drawn off by an exhauster; the residual coke, which is a by-product, is removed at intervals and replaced by a charge of fresh fuel. The principal use of this gas is for illumination purposes. "Bench," "coal," "city," "illuminating," and "artificial," are some of the terms sometimes applied to this gas.

Coke-oven gas is evolved in the manufacture of coke in by-product ovens, and is quite similar in composition and method of manufacture to retort gas. The method of manufacture differs in this respect, that the gas is the by-product and the coke the main product, which is the reverse of retort gas.

Water gas is made by bringing steam in contact with incandescent carbon. It consists essentially of hydrogen and carbon monoxide. The fuel is first blown up by an air blast, and then steam is introduced for a short time; this will cause the fire to cool rapidly and necessitates frequent reblowing. As a result, the process is intermittent.

Carburetted water gas consists of ordinary water gas into which some hydrocarbons, such as oil or naphtha, have been injected to make the gas luminous.

Oil gas is made by vaporizing oil passed through highly heated tubes.

Blast-furnace gas is the waste gas evolved in the ordinary blast furnace, which is simply a huge gas-producer. The gas is quite similar to producer gas.

Producer gas is the gas resulting from the gasification of solid fuel where the heat required in the process is obtained by a partial combustion of the fuel itself.

From the preceding, it will be seen that producer gas has several competitors. Yet it is the most extensively used artificial fuel gas in existence.

A large amount of experimental and inventive work has been done on the manufacture of gaseous fuels. The path has been strewn with failures, and this field of industrial development has become the graveyard of abandoned fuel-gas processes and shattered hopes of immature and visionary enthusiasts who have not understood the problem in all its phases. There is no such thing as chance or luck in the inventive world. All results are the consequence of the operation of definite laws. The supremacy of one system of fuel-gas manufacture over its competitors must be due to certain definite causes and effects. The proper appreciation of the advantages of producer gas requires that we should know the real reasons why it has been able to surpass all the other fuel-gas processes in the race for commercial supremacy.

A successful fuel-gas process must be *simple, efficient, continuous,* and *flexible.*

Natural gas is restricted to such a limited territory that its extensive use is out of the question. Retort gas requires a definite quality of coal, and a large, complicated plant, and makes a residue which must be disposed of. Coke-oven gas can be made only in a large, complicated plant, and requires the attention of a skilled chemist, and a ready market for the coke. The water-gas process is intermittent, complicated, and not very efficient. The carburetted water-gas process, in addition to having the disadvantages of the straight water-gas process, requires oil for the carburetting. Oil gas is restricted to a very limited territory, since it can be used commercially only where the cost of oil is very low. Blast-furnace gas can be obtained only in connection with the operation of large iron works; hence it cannot be adapted to many localities or conditions.

Producer gas combines simplicity, efficiency, continuity, and flexibility in one compact and harmonious unit. Gas-producers for the manufacture of producer gas are simple in construction; can be used through a large range of sizes; are efficient; do not make a residue to be disposed of; can be used with almost any available fuel; and can be operated continuously. The reasons just given account for the supremacy of the producer-gas process over its competitors.

There has been an unusual demand for a gaseous fuel within the last few years, and this has given the producer-gas industry an unprecedented growth. This demand, and the resulting growth, are due to the advent of the gas engine, the appreciation of the value of gaseous fuel for ceramic and metallurgical operations, and the constant diminution of the natural gas supply. The gas engine, on account of its high efficiency, has many advantages over the reciprocating steam engine or the steam turbine. A gas-engine power plant will give more power from a given amount of fuel than is possible to obtain from a steam power plant. Yet, to be able to compete with the steam engine, the gas engine must be supplied with a suitable and inexpensive gaseous fuel such as we have in producer gas. The highest and most easily controlled working temperatures, perfect combustion—thus eliminating the smoke nuisance—and high fuel economy, are possible only by the use of a gaseous fuel. Since many ceramic and metallurgical operations require such conditions for successful operation, it is evident that an adaptable fuel gas like producer gas has an extensive use in such work. Many industries which in the past have used natural gas for fuel, have started to use producer gas because in many cases the cost of the natural gas has become prohibitive as the supply has diminished.

HISTORY OF PRODUCER GAS

About 1834, Faber du Faur, a German engineer, began using blast-furnace gas for heating furnaces at a German iron works.

This gave such good results that the demand for the gas was greater than the supply furnished by the furnaces. From this he reasoned that it would be desirable to build a low type of blast furnace, omitting the charge of iron and using the furnace only for the production of gas to supply the increased demand. Circumstances prevented Faber du Faur carrying this idea into practice; but he announced it at that time, and several contemporary engineers began working on the problem. The first gas-producer was probably built by Bischof in 1839. It is shown in Fig. 1, and resembles a small blast furnace. A is the ash-pit under grate B; C and D are cleaning doors, the former being made with openings to admit the air; E is the body of the producer; F and G are doors for charging the producer with fuel; H is the gas exit; I shows a peep-hole for examining the condition of the fire. The producer was connected to a furnace, from which it received the necessary draught.

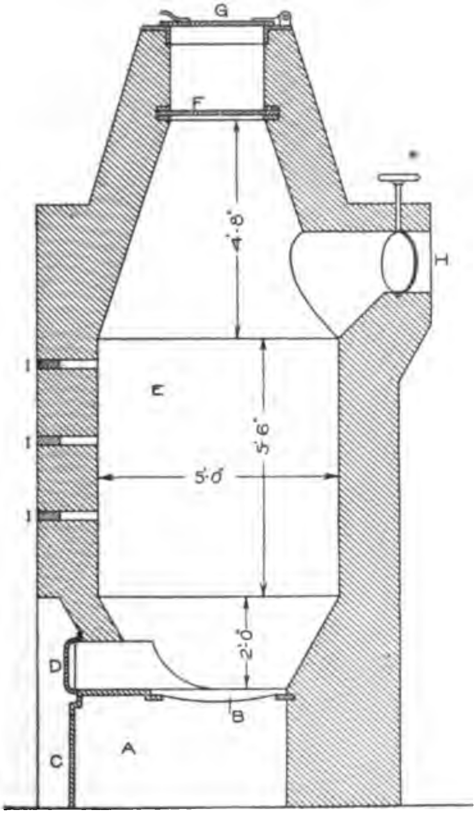


Fig. 1. First Gas-Producer.

Ekman in Sweden, Wedding in Germany, Ebelmen in France, and Siemens in England, were also working on the problem between 1840 and 1860; and they all built certain types of producers. Ebelmen anticipated several present-day types of producers.

The first producer to be used to any extent was the Siemens, which was introduced in England about 1860. This forms the commercial starting point of the producer-gas industry. Dowson, in 1878, was the first to use producer gas for power purposes. The suction gas-producer was introduced on a commerical scale by Benier in France, in 1895.

MANUFACTURE OF PRODUCER GAS

Introduction. The simplest form of producer gas consists of a mixture of nitrogen and carbon monoxide. That is, when a bed of charcoal or coke is blown with a dry air-blast, the fuel bed will soon be at a white heat, when the following reaction will take place:

$$\text{(1)} \qquad C + \underset{\text{air}}{(O + N)} = CO + N.$$

In case carbon dioxide is formed, it should be immediately converted into the monoxide, on account of the excess of incandescent carbon. Thus:

$$\text{(2)} \qquad CO_2 + C = 2CO.$$

The heat required for gasification is that which is evolved in burning the carbon to carbon monoxide. The heat available in the gas is that which will be evolved when the carbon monoxide is burned to carbon dioxide. The heat loss by this method is very high, as is shown by the following example:

1 lb. C burned to CO_2 evolves 14,500 B. T. U. = Heat in fuel
1 lb. C " " CO " 4,450 " = " lost
10,050 " = Available heat in gas (about 70 per cent).

On account of the high heat loss, the use of simple producer gas is now obsolete. The judicious use of steam will not only curtail this loss, but will also increase the heating value of the gas, and will eliminate some of the difficulties of producer operation. Thus a small amount of water gas is made along with the producer gas. In some producers, the fuel undergoes a partial destructive distillation before going onto the fuel bed proper. Hence, modern producer gas is nearly always made in a trinity of processes, the best features of the retort, water, and producer-gas processes being combined into one simple, continuous, and efficient process. This combination of the best elements of other systems is the secret of the extensive present-day use of producer gas.

Gas-Producer. This term is applied to the apparatus in which producer gas is made. It is not, however, very satisfactory, since it fails to be mutually inclusive and exclusive, which is the fundamental requirement of a satisfactory descriptive name. The term is frequently applied to apparatus that is used for making gases other than producer gas. Although evidently unsatisfactory, the term has been in use so long that it is now impossible to replace it with a more rational one.

Typical Producer. A typical producer is shown in Fig. 2. It consists essentially of a steel jacket A; fire-brick lining B; support C; grate E; tuyère F; air blast H; charging hopper J; poke-hole K; and retort L. In American types, L is usually omitted; but it is used quite extensively in European types. Frequently the grate is omitted and the fuel rests directly on the ash-pan bottom.

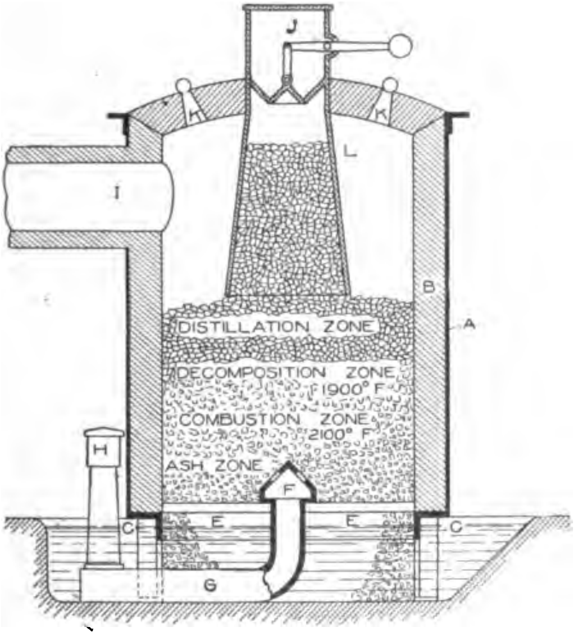


Fig. 2. Typical Gas-Producer.

Steam Blowers. The steam and air should be introduced together so as to secure a thorough admixture. In a large number of producers, the air is forced into the producer by a steam blower, which is simply an air-injector. Since a small quantity of steam must carry in a large quantity of air, the area of the surface of contact between the two should be as large as possible, for "the quantity of air delivered per minute by a steam jet depends upon the surface of contact between the air and the steam, irrespective of the steam pressure, up to the limit of exhaustion or compression that the steam jet is capable of producing." To secure this, the steam jet should be very thin and of annular form. There are two general types of steam blowers—the *solid-jet* type, shown in Fig. 3; and the *annular-jet* type, shown in Fig. 4. Referring to the former, it will be seen that there is a very small area of surface contact between the air and steam; and as a result, this form of blower is very efficient. The annular type will deliver several times as much air with a unit quantity of steam as the solid-jet type.

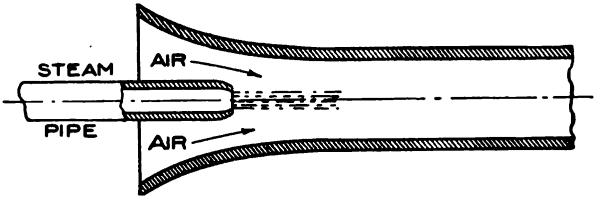


Fig. 3. Steam Blower—Solid-Jet Type.

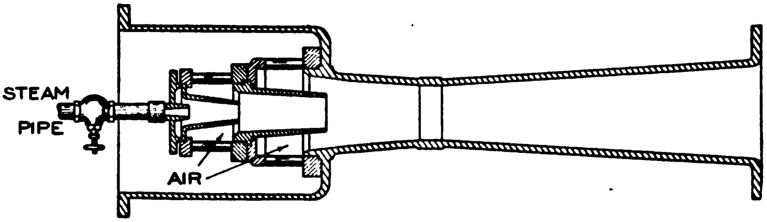


Fig. 4. Steam Blower—Annular-Jet Type.

Chemical Action in Gas-Producer. This is not complicated, and will be understood more readily by considering each successive step. Fig. 2 shows the fuel bed divided into four zones. In practice, the line of demarcation between the different zones is not always distinct, and they sometimes overlap one another.

No reactions take place in the *ash zone,* but it serves to protect the grate from the intense heat of the upper zones, and also preheats the air-blast.

The *combustion zone* receives its name from the fact that the heat required for gasification is generated there by the combustion of the carbon, which burns to carbon dioxide. Thus:

(3) $C + 2O = CO_2$.

The intense heat generated there keeps the superimposed zone at its proper working temperature.

The *decomposition zone* receives its name from the fact that the steam from the blast, and the carbon dioxide from the combustion zone, are there decomposed. Thus:

(4) $H_2O + C = 2H + CO$.

$(2 + 16) + 12 = 2 + (12 + 16)$ atomic weights.

$(1 + 8) + 6 = 1 + (6 + 8)$ proportion of atomic weights.

(5) $CO_2 + C = 2CO$.

The zone must contain an excess of incandescent carbon, and must be kept above 1,800 degrees Fahrenheit, in order that these reactions may take place. Since the decomposition of the steam will absorb a large quantity of heat, it is evident that only a limited amount may be used, if the operation of the producer is to be continuous. By equation 4, 6 lbs. of carbon will be burned to carbon monoxide, evolving 6 × 4,480 = 26,880 B. T. U.; 1 lb. of hydrogen will be separated from 8 lbs. of oxygen, the two being in the form of 9 lbs. of steam, and this will absorb exactly the same amount of heat that would be given off in the combustion of 1 lb. of hydrogen—namely, 62,100 B. T. U. The heat absorbed by the reaction will equal 62,100 − 26,880 = 35,220 B. T. U. for every 9 lbs. of steam decomposed, or 3,913 B. T. U. for every lb. of steam.

The *distillation zone* is so named because the heat from the lower zones effects a partial distillation of the fresh fuel in that zone. The addition of a charge of fresh fuel will always lower the temperature, and this will change the composition of the resulting gas. High temperatures in this zone are conducive to the formation of fixed gases, while low temperatures will be sure to produce a large yield of tar.

Working of Gas-Producer. The temperature of the gas as it leaves the producer should be kept low, or else the sensible heat loss due to the cooling of the gas between the producer and the place of use will be high. This is especially true where the gas contains condensible constituents such as tar which will be deposited in the carrying pipes if the distance is considerable. This will not only mean a heat loss, but will cause trouble in clogging the pipes.

The advantages of *hot* and *cold* gas for heating purposes have been vigorously debated in the past. Both sides have certain advantages; but the conclusions are in favor of cool gas, especially if the cooling may be done in such a way as to utilize the sensible heat extracted. The producer should be so arranged that the sensible heat of the gas may be utilized for preheating either the fuel or the air. The pipes for carrying hot gas must be larger than those for cold gas, since the thermal energy of a cubic foot of gas when it is cold is distributed through about two cubic feet when the gas has a temperature of 800 degrees Fahrenheit. The valves and dampers for handling hot gas must be water-cooled to prevent warping. Further, for gas-engine work the sensible heat is of no value, and the gas should be cooled when it goes into the engine cylinder.

Preheated air will not only conserve the heat losses, but will also induce better gasifying conditions. Combustion with preheated air will be much more intense than with cold air; and as a result, higher temperatures can be obtained. The waste heat in the gas engine exhaust should be used for this purpose when a producer furnishes the gas for the engine. By such an arrangement, in many cases, the efficiency of the producer can be increased ten per cent.

The temperature of the fire is of the greatest importance. A satisfactory operation of the producer can never be secured unless the different zones are kept at their proper temperatures. Low temperatures are conducive to the formation of small amounts of carbon monoxide, and large amounts of carbon dioxide and water vapor, thus causing a heavy heat loss, since the last two are not only diluents, but also represent a certain heat loss in the producer. An excess of steam will be sure to cause a reduction of temperature. Fig. 2 shows the proper temperatures for the different zones. The effect of different temperatures on the composition of the gas, is shown in Table 3 which is taken from an actual test:

The steam acts as a *carrier* of heat energy between the producer and the chamber in which the gas is to be burned. All the heat absorbed from the producer in the decomposition of the steam and in the formation of hydrogen will be given out when the hydrogen is burned back to water. That is, when steam is used, a certain amount of sensible heat that would otherwise be wasted in the producer-gas process is locked up temporarily in the form of hydrogen, and carried over into the combustion chamber, where it becomes available. Under no circumstance can the use of steam cause a gain of heat, and the tendency will always be to chill the fire. The primary function of steam is to induce better gasifying conditions in the producer. In addition to the conservation of the heat losses in the process of gasification, the steam has a very desirable mechanical effect on the fuel bed, by softening the clinkers, preventing localized combustion and the fusing of the clinkers to the brickwork, keeping the fuel bed porous and homogeneous, and protecting the grate by keeping the intense combustion away from it.

TABLE III

Effects of Temperature on Action of Steam

TEMPERATURE F.	PERCENTAGE OF STEAM DECOMPOSED	GAS ANALYSIS		
		CO_2	CO	H
1,245	8.8	29.8	4.9	65.2
1,750	70.2	6.8	39.3	53.3
2,057	99.4	.6	48.5	50.9

This table shows the importance of keeping the temperature of the combustion and decomposition zones near 2,000 degrees Fahrenheit, if satisfactory results are to be obtained.

The producer should be supplied with all the steam that it can decompose, in order to secure a high efficiency. This maximum quantity will vary with the nature of the raw fuel, with the type of producer, and with the method of operation. Excess of steam should be guarded against, as it will cool the fire and will produce a gas with a large amount of water vapor. This water vapor, on account of its high specific heat, will cause a large heat loss when the gas is burned.

Fuel. Practically every known solid fuel has been successfully used for the manufacture of producer gas. The purpose for which the gas is to be used, and the type of producer, will, however, determine what fuels may be used in each particular case. Since each fuel will give the gas certain definite properties, it is evident that the producer gas made from different fuels may vary perceptibly in composition. Thus, the producer gas made from bituminous coal will be high in easily condensible hydrocarbons generally spoken of as "tar;" while that made from anthracite coal will have a low percentage of tar. Thus, some fuel with a certain type of producer might make a quality of gas that would give good results in a steel furnace; while this same gas might be worthless for use in a gas engine. Impurities in the raw fuel will in certain cases give the resulting gas certain constituents that would make it unfit for certain kinds of work. Thus, in burning certain ceramic products with producer gas made from fuel containing volatile sulphur compounds, ammonium salts, or other impurities, considerable difficulty may be experienced from the action that the gas may have on the particular product under treatment. The chemical reactions of the flame, and especially the volatile impurities, may have such a deleterious effect on the product being burned as to make the gas useless for such work. On the other hand, if a muffle-kiln—that is, one in which the combustion products do not come in contact with the ware that is being burned—is used, the impurities would not make any difference. This simply emphasizes the fact that no general rules can be laid down in regard to the kind of fuel to be used for all classes of work, but each individual case must be studied by itself.

The size and condition of the fuel are of considerable importance. A crushed coal will always give better results than coal with large lumps. When large lumps are placed on the fire, considerable time is required for the fire to disintegrate them, and they will always induce adverse gasifying conditions. Some run of mine coal is now being used in gas-producers; but it must be remembered that not all things that are possible are desirable. The use of fine dust, also, is not good practice. The fuel should be dry, since any moisture that it contains must be driven off in the producer, and this will cause a certain heat loss. Anthracite, bituminous and brown coal, peat, lignite, wood, sawdust, shavings, tanbark, and similar refuse, have all been used for making producer gas.

Nomenclature and Definitions. Several absurd terms have crept into use, probably due to the fact that the producer-gas industry is the result of the labors of many men covering a period of nearly three quarters of a century and working from different points of view. The prefixing of either the name or the type of the producer to the gas made therein, is positively wrong and should never be done. That is, expressions like "Siemens gas," "Dowson gas," "Mond gas," and "suction gas" should never be used. In the first three examples, the name of the designer of the producer, and in the last one, the name of the type has been prefixed to the gas. The absurdity of this becomes evident when we use similar terms in connection with steam and steam boilers. For example, the steam made in a Stirling boiler would be called "Stirling steam;" and if a return tubular were used, the steam would be called "return tubular steam"—terms so absurd as not to need further emphasis. It was originally thought that each design or type of producer would make a gas with a certain distinctive quality. It is true that the gas made in different producers will vary in composition; but this variation is due to the method of operation or to the nature of the raw fuel used, rather than to the name or type of producer.

To avoid any further ambiguity, the following definitions are given, the close observance of which will save a large amount of trouble and misunderstanding:

A *pressure gas-producer* is one which has the blast introduced under pressure; this may be done either by a steam or a power blower.

An *induced-draft gas-producer* is one in which the resulting gas is induced away from the producer; the interior of the producer is kept at less than atmospheric pressure, and the air is forced in by the pressure of the outside air. The inducing action may be obtained by a chimney, steam ejector, gas-engine piston, or exhausting fan.

A *natural-draft gas-producer* is an induced-draft gas-producer in which the inducing action is accomplished by a chimney.

A *suction gas-producer* is an induced-draft gas-producer in which the inducing action is accomplished by a gas-engine piston. That is, the gas engine draws its gas directly from the gas-producer on the charging stroke of the engine. The term "suction gas-producer" has frequently been incorrectly applied to other types of producers.

A *water-seal gas-producer* is one which is so constructed as to have a seal of water between the interior of the producer and the atmosphere.

A *continuous gas-producer* is one that may be operated continuously for a long period of time. To secure this condition, the fuel must be introduced, and the ashes removed, in such a manner as not to interfere with the process of gasification.

An *automatic gas-producer* is one that is so constructed and operated as to keep automatically a fixed supply of gas stored in a holder.

A *down-draught gas-producer* is one that removes the gas from the bottom, and introduces the air-blast at the top of the fuel bed, and in this way causes the draught and the resulting combustion to go downward. The term *inverted-combustion* is also used synonymously for *down-draught*.

A *by-product gas-producer* is one that, in addition to the regular production of gas, makes one or more auxiliary products based on certain constituents of the raw fuel or resulting gas, constituents that generally would otherwise be lost.

An *underfeed gas-producer* is one in which the fresh fuel is fed into the bottom of the producer.

GASIFICATION LOSSES

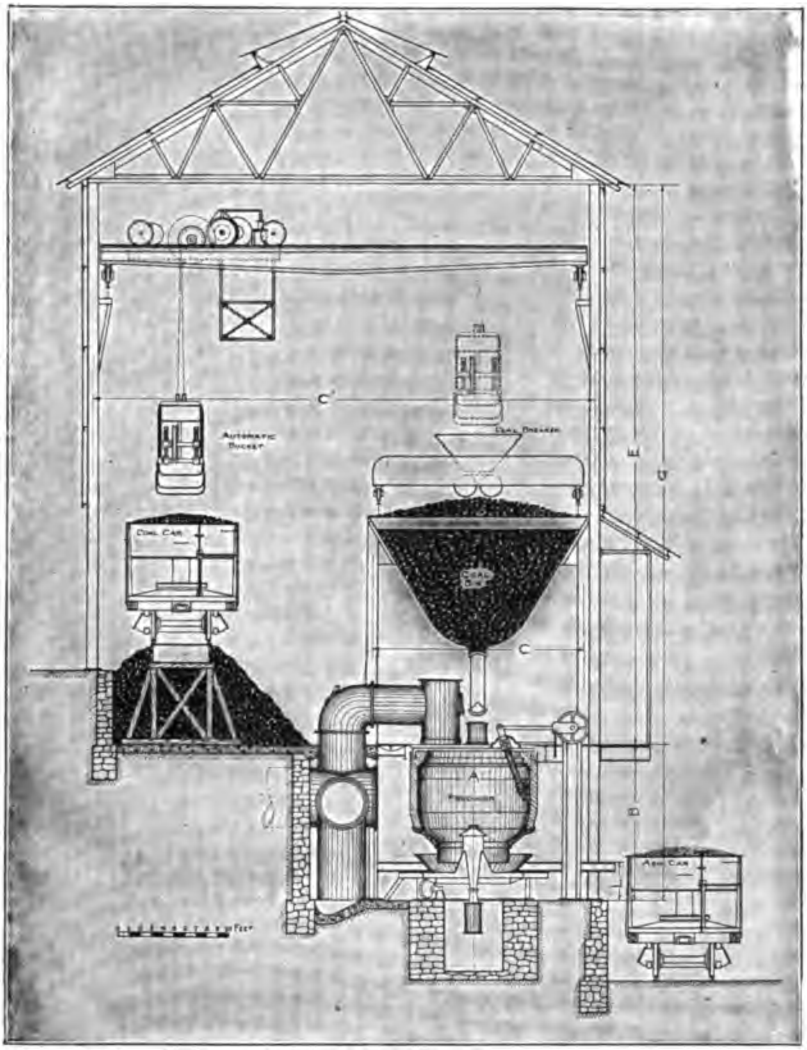
Efficiency. Since producer gas is made by a partial combustion of the fuel itself, it is evident that there must always be a certain loss in the process of gasification; and, as a result, the efficiency of the gas-producer will always be less than unity.

$$\text{Efficiency} = \frac{\text{Heat units in gas from a unit weight of fuel}}{\text{Heat units in a unit weight of fuel}}.$$

With a properly designed and carefully operated gas-producer, the gasification loss should not be over 20 per cent; that is, the efficiency should be at least 80 per cent. Thus, if the fuel contained 14,000 B. T. U. per pound, and the gas evolved from a pound of that fuel contained 11,200 B. T. U., then the efficiency would be equal to $\frac{11,200}{14,000} = .8$, which is the equivalent of 80 per cent.

The heat energy in the gas will be of two forms—heat of combustion and sensible heat, by virtue of the temperature of the gas. Since the latter will be lost if the gas is cooled down to atmospheric temperature, it is evident that a gas-producer will have two efficiencies, depending upon whether the gas is used hot or cold. The former is called the *hot-gas efficiency*, while the latter is called the *cold-gas efficiency*.

Since the heat units in the gas can come only from the carbon actually gasified, evidently, if some carbon passes through the pro-



HUGHES MECHANICALLY-POKED CONTINUOUS GAS PRODUCER
Coal Handled from Cars by Overhead Traveling Crane with Automatic Bucket

ducer without being converted into gas, a certain correction must be made to get the true efficiency of the producer. The grate efficiency represents the percentage of carbon actually gasified. Thus, if the grate efficiency is 96 per cent, it means that 96 per cent of the carbon charged into the producer is gasified, and 4 per cent passes out with the ashes. The true efficiency of the producer will be the product of the grate efficiency and the efficiency as first determined. Thus, if the efficiency as first determined—or, which is the same thing, the apparent efficiency—is 80 per cent, and the grate efficiency is 96 per cent, then the true efficiency of the producer is 80 per cent × 96 per cent = 76.8 per cent.

To determine the efficiency of a gas-producer, it is necessary to have the chemical analysis and temperature of the gas, experimental determination of the calorific value of the fuel, and the percentage of carbon passing out with the ashes. The chemical work must be done by a skilled chemist, and the engineering work by a skilled engineer, if satisfactory results are expected. In brief, a careful test of the gas-producer must be made, in order to determine its efficiency.

Testing Gas-Producer. The correct testing of a gas-producer is of the greatest importance. In order that the results of any test may be comparable with other tests, it is desirable that all testing should be done in accordance with a fixed code. The essential points are as follows:

Before the test is begun, the producer should be examined very carefully, and a record made of all the principal dimensions. All the apparatus used in the test must be calibrated. The producer must be in operation for several hours before the test is started, so as to insure that it is heated up to its working temperature. The test, to be of value, should be continued for at least twelve hours. All the conditions during the test should be as nearly uniform as possible.

When the test is stopped, the height and condition of the fire in the producer should be as near the height and condition at starting as it is possible to have them. The sampling of the fuel, ashes, and resulting gas is of the utmost importance, since the value of the test depends primarily upon the accuracy and care with which the samples are secured. A careful record should be kept of all events connected with the test. All the readings or observations should be so secured as to make their interpretation at any future date an easy matter.

If the test is conducted along the general lines just mentioned, the data obtained from it will be valuable in that it will show whether the producer is doing its best. In many cases, by making suitable changes, the efficiency of the producer can be materially increased.

Heat Losses. Usually there are eleven heat losses in the process of gasification. By judicious management, each of these may be reduced to a very small quantity. It is seldom possible to reduce any one loss to zero. The principal losses will now be given.

Sensible Heat Loss. This is the heat carried out by the gas by virtue of its temperature. If the temperature of the exit gases is 1,000 degrees Fahrenheit, this loss will amount to about 11 per cent. If the producer gas is high in hydrogen—on account of its high specific heat—the percentage of loss will be considerably higher. The sensible heat loss is large in nearly all forms of producers, and is a strong argument in favor of a form of construction for the producer whereby the gas is cooled before it leaves the producer, thus securing a conservation of this heat energy.

Carbon Dioxide Loss. The loss due to the formation of carbon dioxide is frequently high; in some cases this may amount to 10 per cent.

Heat Balance. In order to determine just what the various losses are, it is necessary to collect considerable data during the test. In order that such data shall be of value, it must be secured with a definite end in view. The easiest and most logical way to arrange it is in the form of a balance sheet. That is, the producer is charged with all the heat units delivered to it, and credited with every heat unit that is received from it. In other words, one should run a debit and credit account with the producer; if these are correct, the two sides will balance; that is, they will be equal to each other. The following arrangement of such a heat balance is taken mainly from the author's treatise on *Producer Gas and Gas-Producers:*

DEBIT SIDE		CREDIT SIDE
To heat per pound of fuel		By heat per pound of fuel
Calorific pound of fuel		Calorific power of gas
Heat in air-blast		Evolved in formation of CO
Heat in steam-blast		Evolved in formation of CO_2
		Absorbed in decomposing steam
		Lost in ashes
		Lost in unburned carbon
		Lost in tar and soot
		Lost in sensible heat of gas
		Lost in heating undecomposed steam
		Lost in evaporating moisture in fuel
		Lost in volatilization of hydro-carbons
		Lost in radiation
Sum of debits	=	Sum of credits

The classification of all the losses in a balance like the one just given will show at a glance where any heat unit goes. If any loss is high, it will suggest certain changes in the construction or operation of the producer which will make it possible to curtail the loss in question. There are a large number of producers now in operation where certain heat losses are high; and in many cases this useless waste could be reduced materially by the application of this heat balance to locate the difficulty, and subsequently the utilization of engineering skill to remedy it.

RULES

Specific Heat of Producer Gas. To determine the specific heat of producer gas, multiply the amount of each constituent present by its own specific heat as given in Table II, page 3, and divide the sum of the products so obtained, by 100. The result will be the specific heat per cubic foot of the particular gas in question.

Weight of Producer Gas. To determine the weight per cubic foot of producer gas, multiply the amount of each constituent present by its own weight per cubic foot as given in Table II, page 3, and divide the sum of the products so obtained, by 100. The result will be the weight per cubic foot of the particular gas in question.

Specific Gravity of Producer Gas. To determine the specific gravity of producer gas, first determine the weight of the gas per cubic foot. Then,

$$\frac{\text{Weight per cu. ft.}}{.0807^*} = \text{Specific gravity with reference to air.}$$

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*Weight of air per cubic foot.

Calorific Power of Producer Gas. To determine the calorific power of producer gas, multiply the amount of each combustible constituent present by its own calorific power per cubic foot as given in Table II, page 3, and divide the sum of the products so obtained, by 100. The result will be the calorific power per cubic foot of the particular gas in question.

CLASSIFICATION OF GAS-PRODUCERS

All gas-producers may be classified into the following groups:

1. Pressure.
2. Induced-draught.
    - (a) Draught induced by a chimney.
    - (b) Draught induced by an exhauster.
    - (c) Draught induced by a gas-engine piston—that is, a suction gas-producer.

REPRESENTATIVE TYPES OF GAS-PRODUCERS

Pressure Types. The Amsler gas-producer is shown in Fig. 5. A is the body of the producer, with charging hopper B, and gas-exit C. D is a side poke-hole, to facilitate the breaking of climbers which may adhere to the side wall. E is a steam blower which is connected to the central blast-chamber G, by the pipe F. H is the blast opening. The cross-section of the producer is circular.

The Duff gas-producer is shown in Fig. 6. The main features of this are an inverted V-shaped grate in the middle, which extends from one wall to the other, vertical openings in this grate so as to give the blast a vertical direction, and a rectangular cross-section for the producer. The usual form of water-seal ash-pan is used.

The Swindell gas-producer is shown in Fig. 7. H is a charging hopper; N is the gas-exit; G is an inclined grate; C is a cleaning door. The blast is introduced by the usual form of steam blowers, although these are not shown in the illustration, and enters the ash chamber by the pipes S. A P is the usual form of water-seal ash-pan. A careful inspection of this producer and the ones shown in Figs. 5 and 6 will reveal a marked similarity in principle of grate construction. The Duff gas-producer has an inverted V-shaped grate of rectangular cross-section; the Amsler gas-producer has an inverted V-shaped grate of circular cross-section; and the Swindell gas-producer has a V-shaped grate.

The Forter gas-producer is shown in Fig. 8. A is the main body of the producer and has a gas-exit B. C is the usual form of charging hopper, while D is a poke-hole. E is a leg for supporting the producer. F is an inclined bosh wall which has the blast-chamber G. H is an opening for the blast to pass from G to A. I is a door for cleaning G. K and L are steam blowers. M is the central blast pipe with hood N. J is side poke-hole.

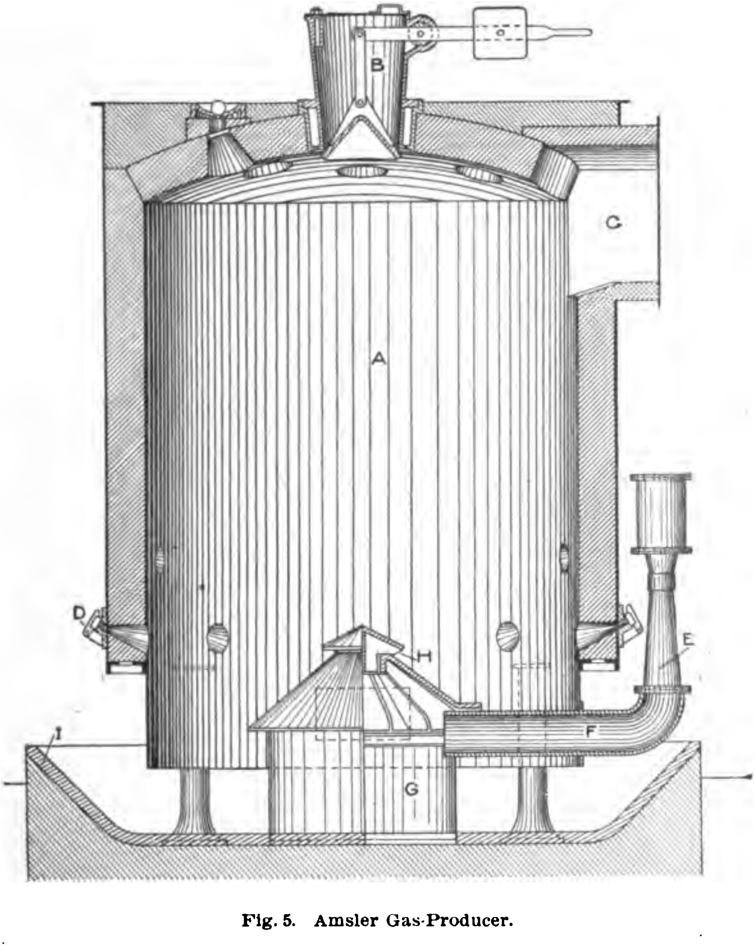
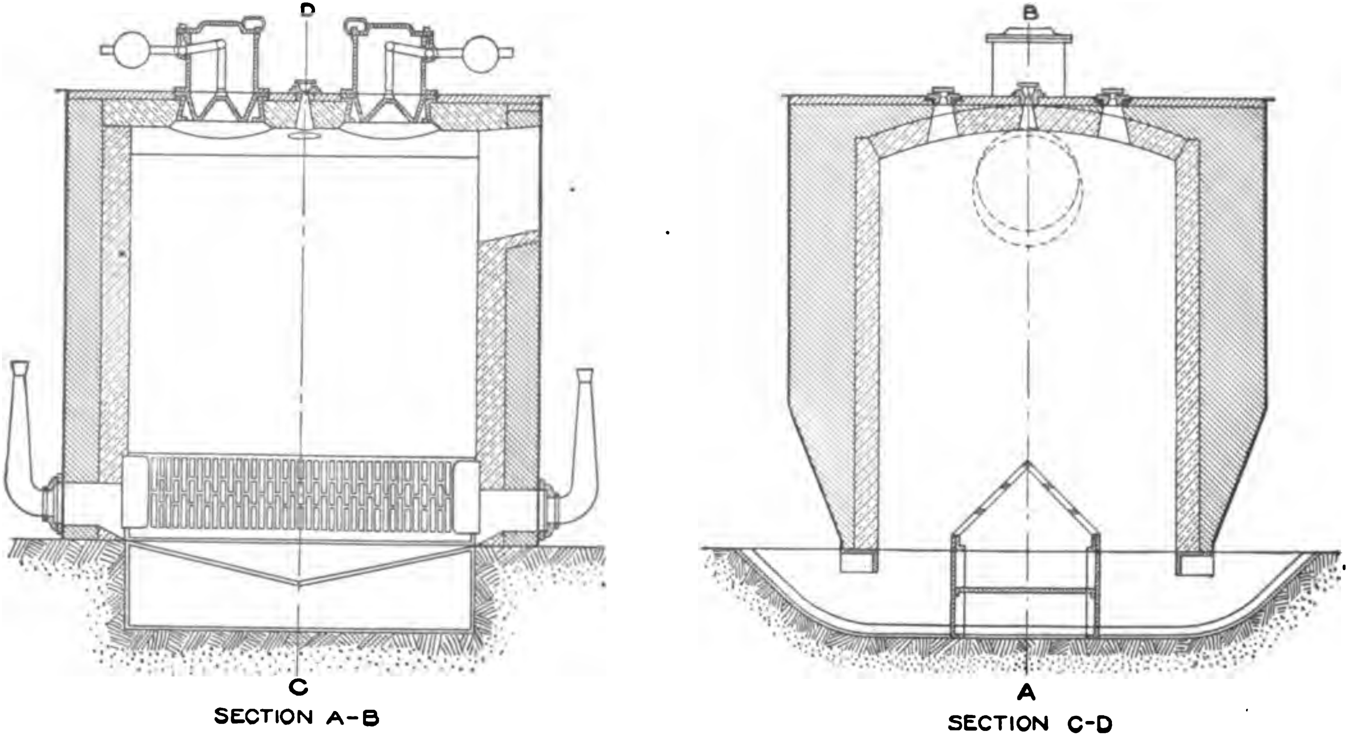


Fig. 5. Amsler Gas-Producer.



SECTION A-B

SECTION C-D

Fig. 6. Duff Gas-Producer.

The Fraser and Talbot gas-producer is shown in Fig. 9. In construction and method of operation this producer differs radically from the usual practice. The poking of a gas-producer is very laborious, and men will usually shirk it whenever possible. The primary object of this producer is to eliminate the hand-poking entirely. A is a central shaft that is operated by motor B. In addition to a slow rotary motion, A is also given an up-and-down motion by crank C and connecting rod D. E is a water- or steam-cooled poking-arm that is fastened to A. The upper position of E is indicated at F. H is a frame for supporting the driving mechanism. I is the blast pipe which is supplied with air and steam by a blower on the outside. J is a bosh plate, and K is the bottom of the water-seal ash-pan. L is

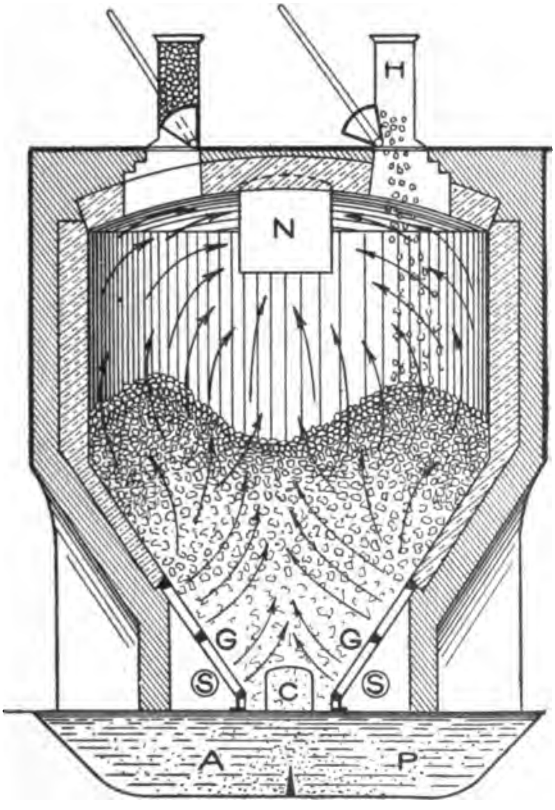


Fig. 7. Swindell Gas-Producer.

a coil spring so arranged that if E should strike a hard clinker, it will allow the poking arm to slide past it. In this way the danger of

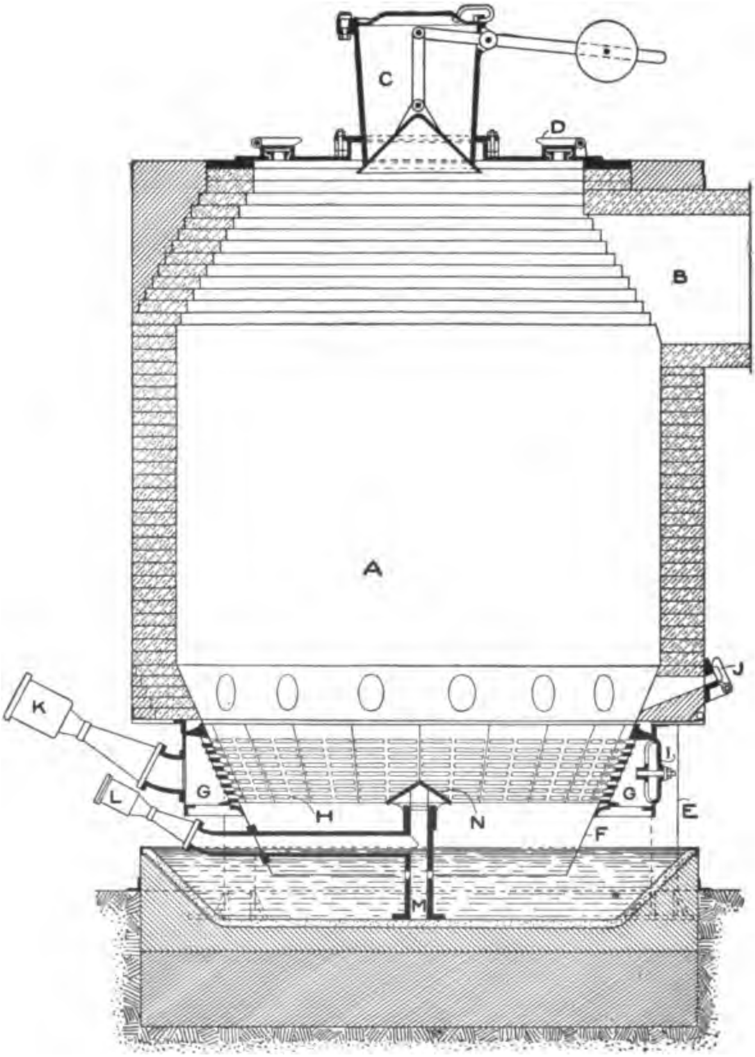


Fig. 8. Forter Gas-Producer.

the breakage of E is in a large measure eliminated. M is an ordinary charging hopper. By means of the rotary and up-and-down motion

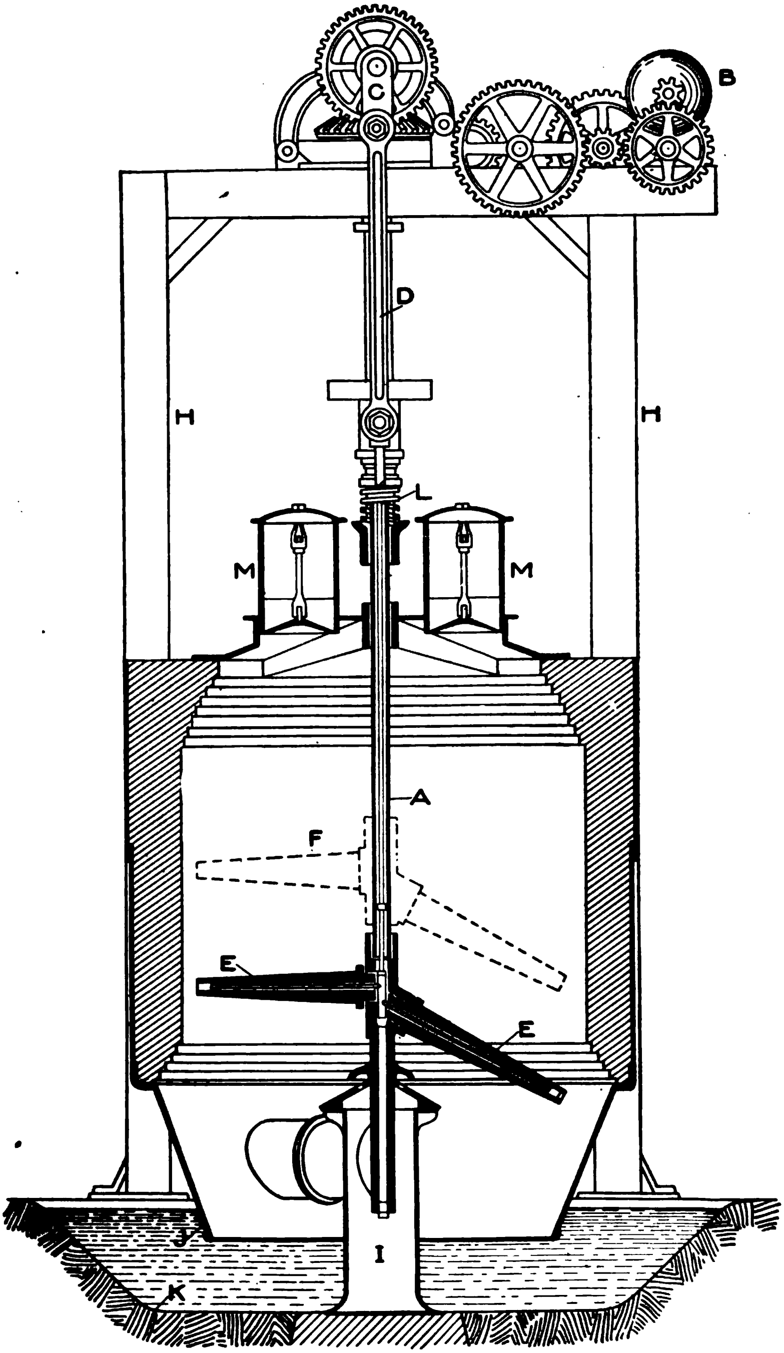


Fig. 9. Fraser and Talbot Gas-Producer.

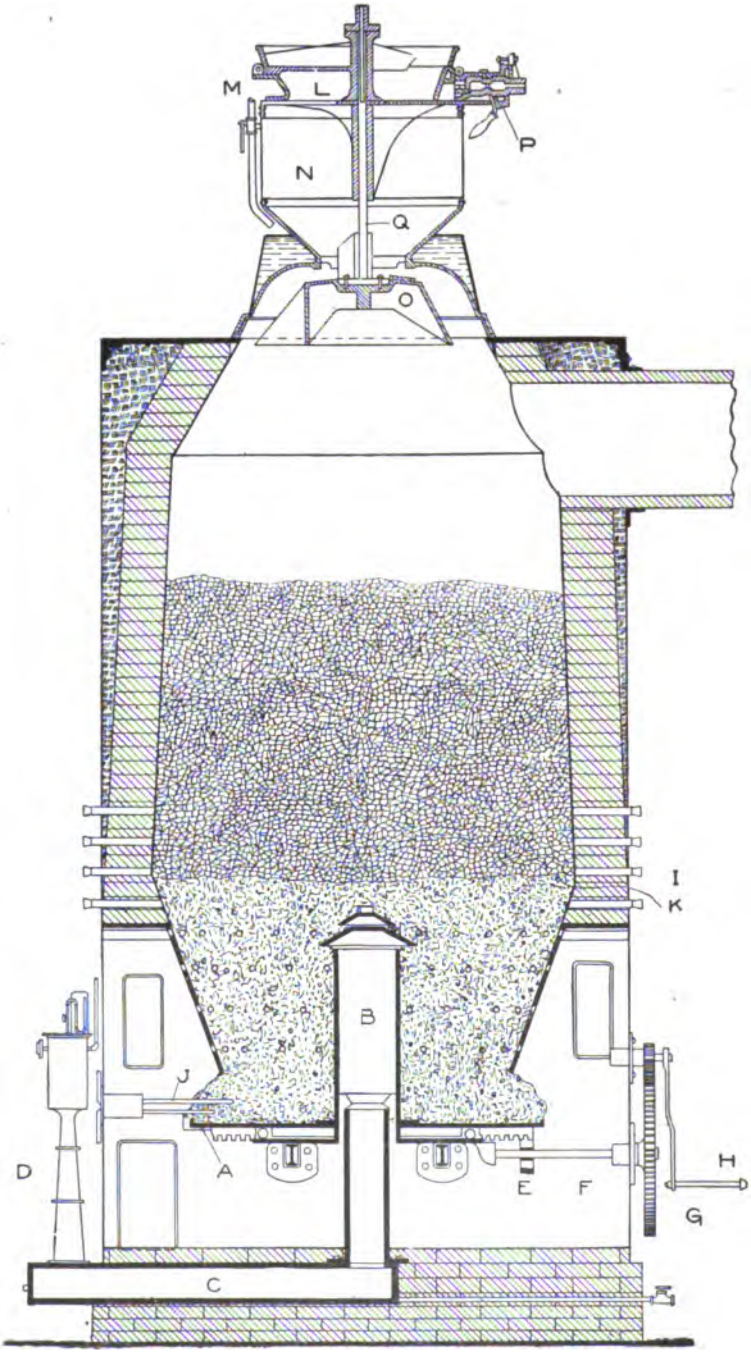


Fig. 10. Taylor Gas-Producer.

of E, a very thorough agitation of the fuel bed is secured without any hand labor.

The Taylor gas-producer is shown in Fig. 10. The essential features of this producer are a revolving grate, the use of a thick bed of ashes to prevent the burning out of the grate, and a high, central blast pipe which introduces the blast at the upper surface of the ash bed. The producer is equipped with the Bildt automatic feed, which introduces the coal in a thin, continuous stream and that without any hand labor. A is the circular grate that revolves around the central blast pipe B. C is a pipe connecting B with the steam blower D. E is a pinion on shaft F, that has the gear teeth which mesh with E, and by turning H, A will be revolved. I is a peep hole for observing the height of the ash-bed. The division between the fuel and ash-bed is shown at K. J is a finger which drags the ashes off of A as it is rotated. The Bildt automatic feed consists essentially of a hopper L into which the coal is primarily deposited, a register valve M, which controls the amount of coal going to the tank N below, and a rotating disk O. This disk has sloping sides of varying angles and is so designed as to deposit the coal evenly over the charging area. O is rotated by means of a special ratchet motion P and the vertical shaft Q. The coal is supplied to the hopper L by any convenient means and dropped into the storage tank N as needed. The tank N may be made of considerable capacity, but three hours supply is usually enough. The disk O has a slow, rotating motion and causes the coal to work out of N and fall over the edge of O. The speed of O is from 1 to 15 revolutions per hour, the different speeds being obtained by the ratchet P.

The section of the Morgan gas-producer fitted with a George automatic feed is shown in Fig. 11. The automatic feed consists essentially of coal tank and a revolving eccentric chute which spreads the coal out over the surface of the fuel as shown in the illustration. The steam blower is placed in a horizontal position as is shown in the lower left-hand corner of the illustration. Fig. 12 shows the operating floor of a battery of 52 Morgan gas-producers. A small, auxiliary coal tank is placed over and above the feeding mechanism of each producer. These tanks are filled by means of the large tank shown on the traveling crane. The plant is a good example of what may be done in the way of using labor-saving devices in a gas-producer installation. Inasmuch as every pound of coal that is used in these 52 producers is handled by mechanical means, it can be seen at once that the labor cost will be very low. Further, gas-producers that are equipped with some form of automatic feeding device will make a more uniform quality of gas and will also usually be more efficient.

The Smythe gas-producer is shown in Fig. 13. This is a radical departure from the usual type of gas-producer in that the grate is made entirely different. A is the main body of the producer with charging hopper B, poke-hole C, and gas-exit D. E is an inclined grate so positioned as to cause the ashes to work down to the lower left-hand corner of the producer and then down into the water-seal ash-pan below. The steam is introduced at a higher point than usual, and in this way it at once comes in contact with the incandescent fuel.

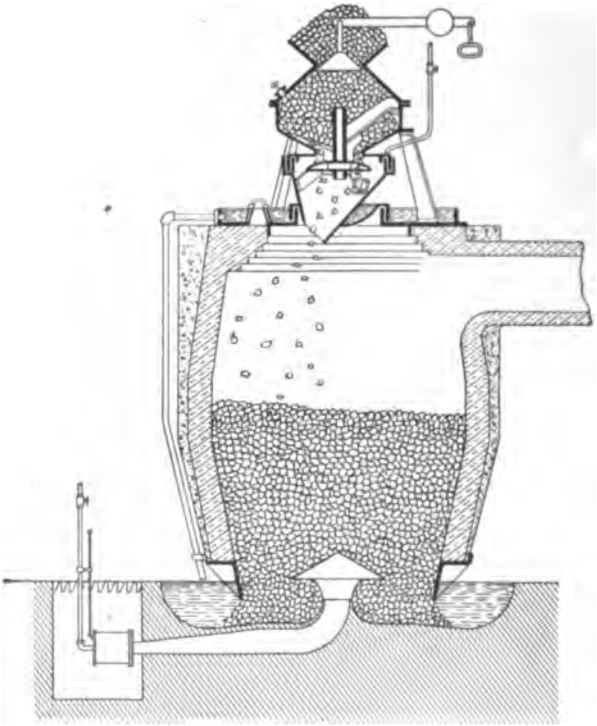


Fig. 11. Section of Morgan Gas-Producer Fitted with George Automatic Feed.

The Poetter gas-producer is shown in Fig. 14. The main feature in this is the use of a device to effect the destruction of the tar in the producer and make a gas with no condensible constituents. A is a retort which is supplied with fresh coal by means of the charging hopper B. The upper end of A is in communication with the ash-zone below by means of pipe C. The blast is introduced at D. E is a water-seal ash-pan, and F is the gas-exit. As the gas is given off from the surface of the fuel, it heats A and the fuel contained therein. A large part of the volatile matter or tar in the coal contained in A will be given off as vapors and then pass out through C and come up through the fuel bed. When these vapors come in contact with the incandescent fuel they will be converted into fixed gases, thus eliminating all trouble from condensation after the gas leaves the producer. This type of producer will give good results when using a coal that contains a large amount of tar, and under those circumstances will make a gas suitable for gas engine use.

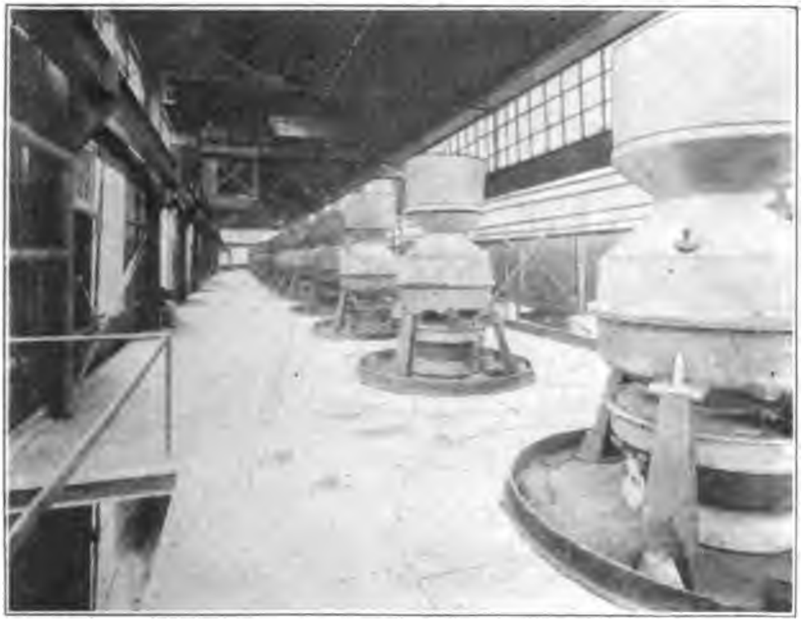


Fig. 12. Operating Floor of Morgan Gas Producer.

The Duff-Whitfield gas-producer is shown in Fig. 15. The main object of the new features in this producer is to secure the destruction of the tar in the producer itself. The unique feature is the circulation of the gases through different parts of the producer. The blast is introduced under the Duff grate A. B is the usual charging hopper, and C is the water-seal ash-pan. The gas-exit is at D. E is a small steam-blower which draws the gases given off from the surface of the fuel away at F and delivers them at the lower part of the fuel bed through opening G. H is a small steam-blower which draws off the gases from the space near the fuel surface by opening I, and delivers them through J at the bottom of the fuel bed. In each case the green gases taken from or near the surface of the fuel

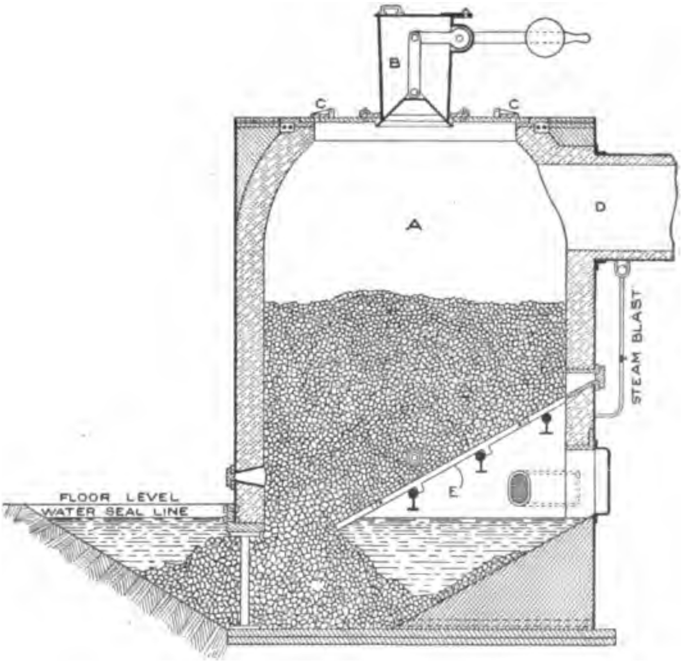


Fig. 13. Smythe Gas-Producer.

are forced up through the incandescent fuel and in this way they are converted into fixed gases. Since the producer secures the destruction of the tar, it is obviously well adapted to make a clean gas from fuel containing large amounts of tar.

Induced-Draft Gas-Producers. The Loomis induced-draft gas-producer is shown in Figs. 16 and 17. Under certain conditions this producer may also be used with pressure. The producers are generally installed in pairs. The producer A is shown in section, while producer B is shown in elevation. The two are connected at the top by the pipe C. D is a vertical, tubular boiler which acts as an economizer by abstracting some of the sensible heat in the gas. E and F are water-cooled valves connecting the bottom of D with B and A. G is an exhauster driven by engine H. K is a tower scrubber with a series of shelves M upon which is placed a layer of coke. L is a pipe connecting D and K, and I connects K with G. Q is a cleaning door for removing the coke from M. N and O are strain pipes for admitting steam under the fire in A and B. P is a door for charging the producers with fuel. R is a seal. S and T are delivery pipes. S goes to the producer-gas holder, and T to the atmosphere. As water-gas may also be made in this producer under certain conditions, another pipe is sometimes placed on R and is used to deliver the water-gas to the water-gas holder. The operation is as follows: The exhauster G being in operation and the valves E, and F and doors P open, the air will enter at P and produce a down-draft combustion in A and B; the resulting gas will pass down and out through E and F, up through D, over to the bottom of and then up through K, out through G and then go to the mains or gas holder. Another way is to have the ash-pit door U open, doors P and valve F closed, then the air will enter at U, pass up through A, and the resulting gas will pass over to B by pipe C, and then pass downward through the fuel bed in B, then out through E and up through D. By either method it is

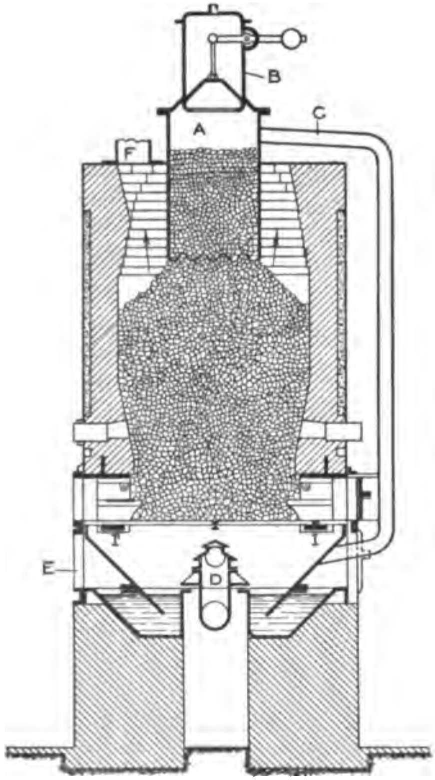


Fig. 14. Poetter Gas-Producer.

evident that all the volatile or easily condensible matter given off from the fresh coal must come in close contact with the incandescent fuel in the middle of the producer, and, as a result, the tar is broken up and converted into fixed gases. In making water-gas the fuel is first brought to the proper temperature by blasting with air and making producer gas; then steam is admitted and water-gas is made for several minutes. When the fire becomes chilled the steam is shut off and the temperature is again raised by making producer gas.

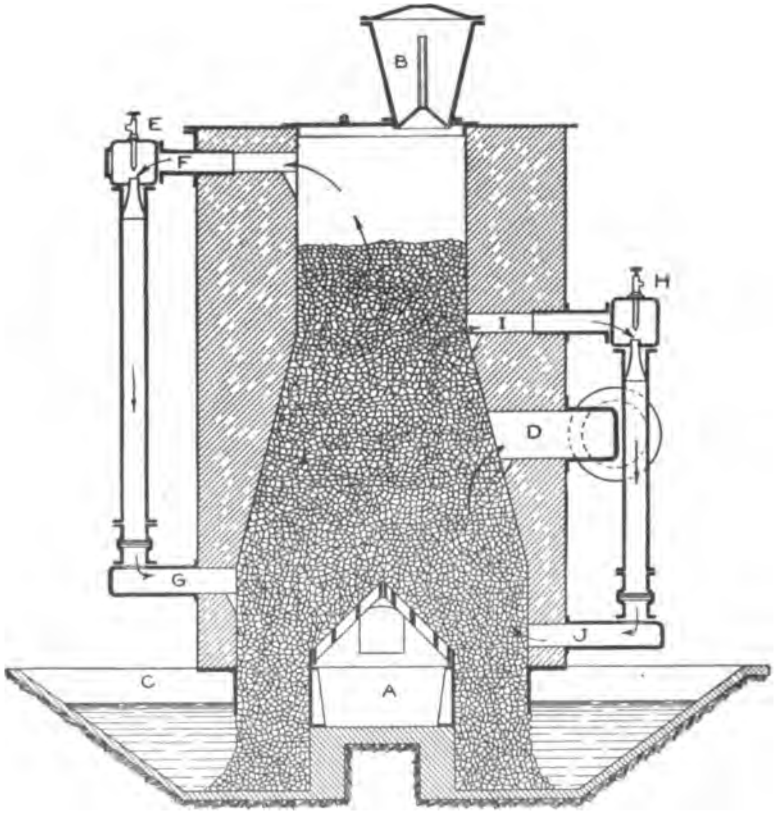
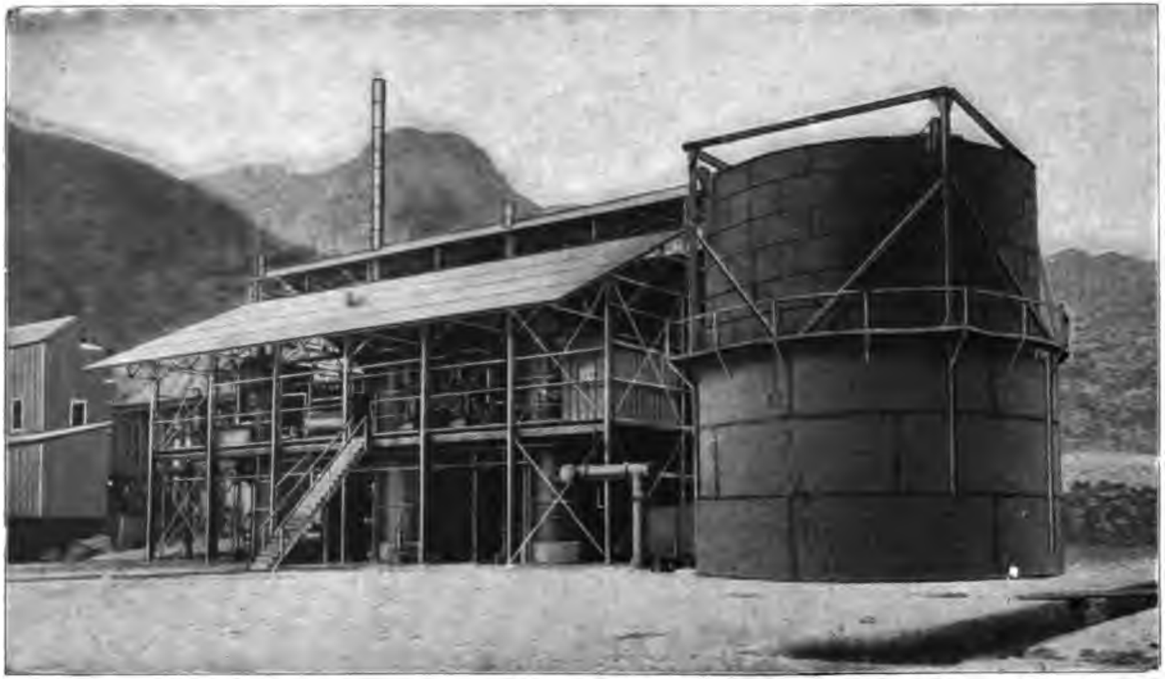


Fig. 15. Duff-Whitfield Gas-Producer.

The Capitaine underfeed gas-producer which is operated by induced draft is shown in Fig. 18. The coal is introduced at A and is then fed over to the center of the producer by spiral conveyor B which delivers the coal to the vertical spiral conveyor C; this, in turn, screws



LOOMIS-PETTIBONE GAS GENERATING PLANT, OF 3000 H. P. CAPACITY the coal up into the center of the fuel bed. The ashes are worked out through grates D, while the gas is withdrawn at E. The primary object of this design of gas-producer is to introduce the fuel in such a manner as to secure a slow agitation of the fuel bed and also compel the volatile products of the green fuel to pass up and through the mass of superimposed incandescent fuel; in this way the volatile matter will be converted into fixed gases. By comparison with Fig. 2 it will be seen that the distillation zone is under the fuel bed in Fig. 18.

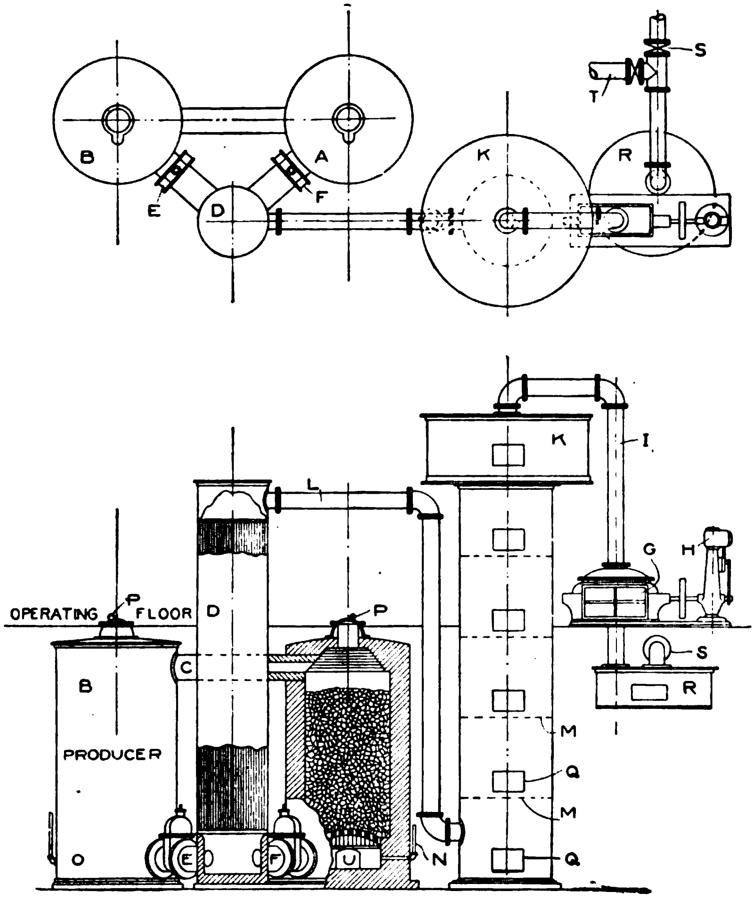


Fig. 16. Loomis Induced-Draft Gas-Producer.

Suction Gas-Producers. These are used entirely for power purposes—that is, for furnishing gas to gas engines. The chemical

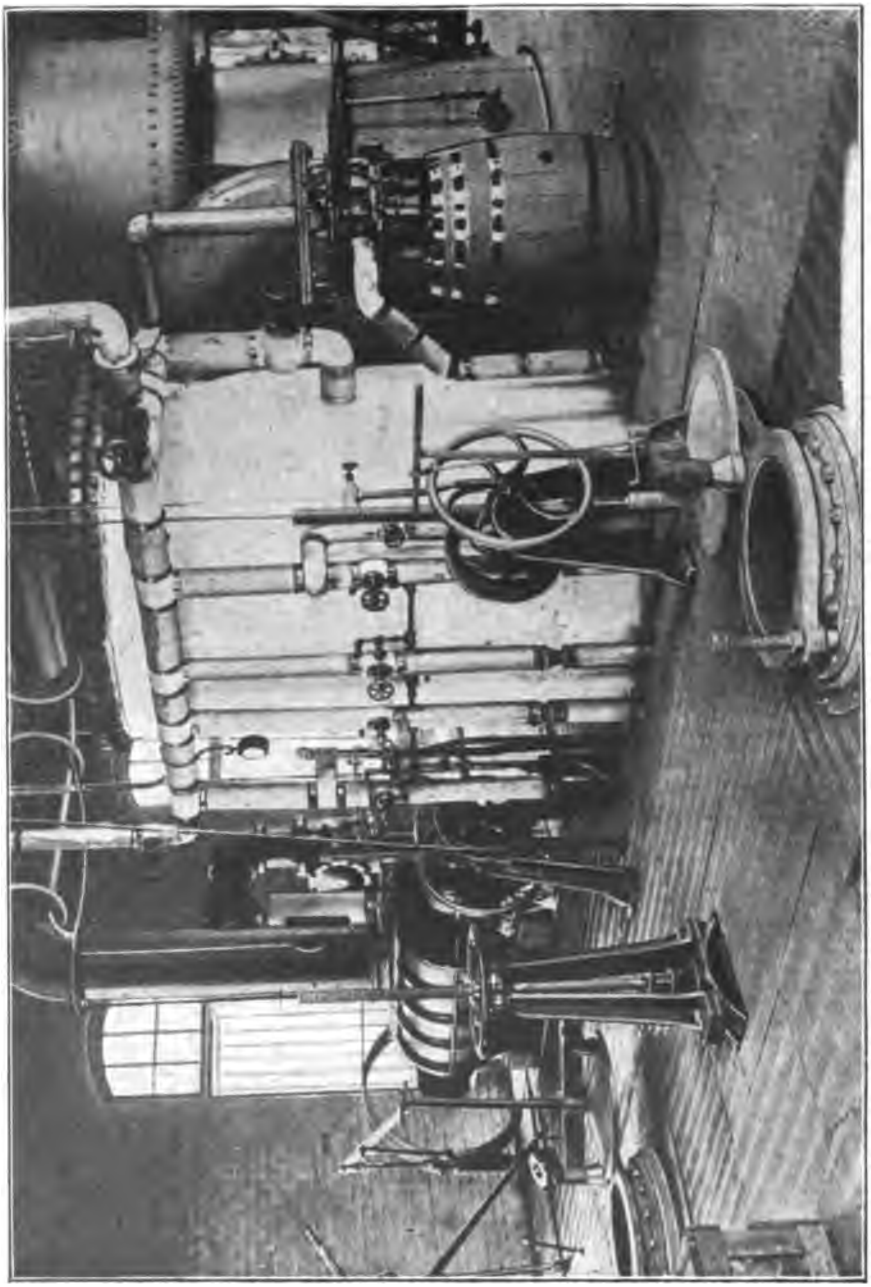


Fig. 17. Operating Floor of Loomis Gas-Producer.

reactions that take place in the manufacture of the gas are the same as for the pressure type of producer. The construction of the suction gas-producer is usually quite different from that of the other types. The two most desired requirements for suction gas-producers are that they shall be *compact* and *self-contained*. As a result each suction producer has its own steam generating apparatus. This apparatus is usually spoken of as a vaporizer, and there are three general ways of using these vaporizers.

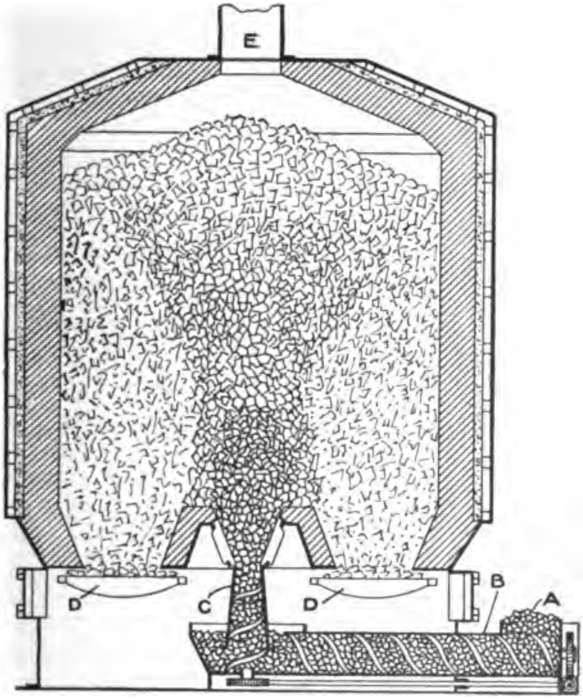


Fig. 18. Capitaine Underfeed Gas-Producer.

First—To have the vaporizer an integral part of the producer, as shown in Fig. 19.

Second—To have the vaporizer attached to the side of the producer, as shown in Fig. 20.

Third—To have the vaporizer entirely separate from the producer as shown in Fig. 23. In the first two cases the water is vaporized by means of the sensible heat in the gas as it leaves the producer; in the last case the sensible heat of the engine exhaust gases is used;

this may be made to return about 10 per cent of heat back to the producer. Inasmuch as the gas must be cleaned before going to the engine, some form of scrubbing apparatus is always used between the producer and the engine. In order that this scrubbing device may be kept simple, practically all suction gas-producers are operated on anthracite coal, which produces very little tar; as a result, the work of the scrubber is generally limited to the removal of fine dust only.

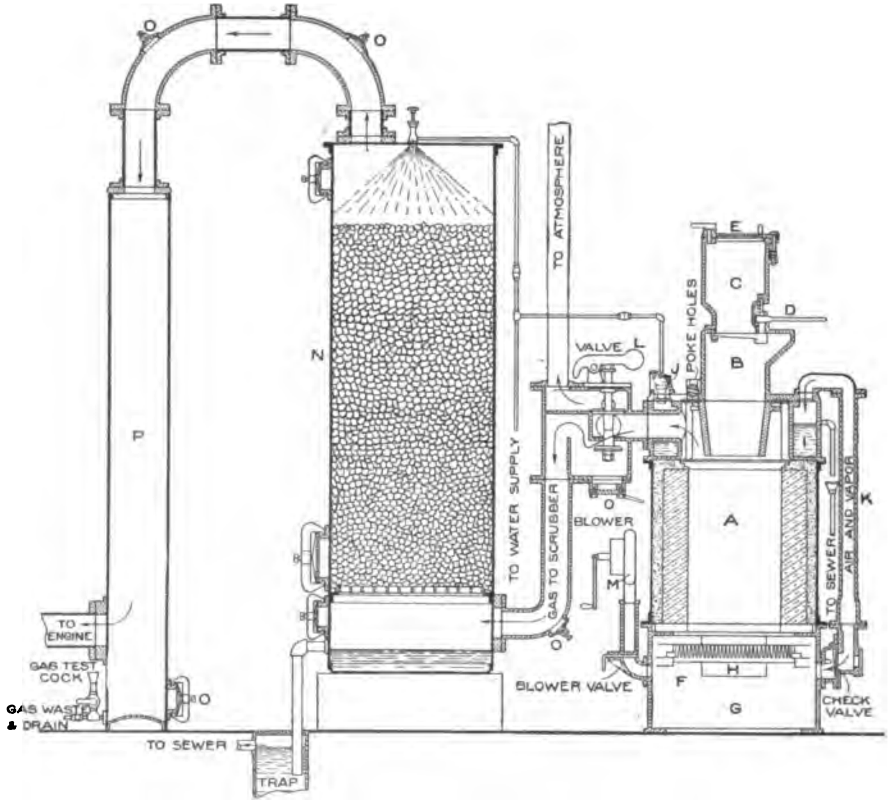


Fig. 19. Fairbanks-Morse Suction Gas-Producer.

The Fairbanks-Morse suction gas-producer is shown in section in Fig. 19. A is the body of the producer with fuel magazine B, hopper C, fuel valve D, and hopper cover E. F is a grate bar over ash-chamber G. H is the ash-door. I is the vaporizer with air inlet J. K is a pipe connecting I with G. O is a hand-hole cover which may be removed either for inspecting the interior of the pipe or for the removal of dirt. L is a valve lever and weight. M is a hand-blower that is used in starting the fire and blasting it up to such a point that the gas evolved will be of the proper quality to use in the engine. N is a scrubber filled with coke and supplied with a spray of water at the top; as the gas comes up through the interstices of the columns of coke it comes in close contact with the water that is trickling down, and, as a result, the fine dust carried by the gas is washed down to the bottom. P is a storage tank placed near the engine. The test cock at the bottom of P is used to test the quality of the gas before starting the engine.

The method of starting a suction gas-producer will now be given. The reference will be made to the producer just described, but the principles may be applied to any other producer. First see that the vaporizer is supplied with water and that the valve under L is open to the atmosphere. To open the valve it will be necessary to turn L over 180 degrees from the position shown in the illustration; then the lower disk on the valve stem will come up against its seat, closing the passage to the scrubber, and the upper disk opening the one to the atmosphere. Place some easily inflammable material, such as oily waste or pine kindling on the grate; set fire to this and add a little coal, in the meantime keeping the ash-door open so as to produce a natural draft. Just as soon as the fire is started nicely, add more wood and coal. Close the ash-door and begin blowing the fire very slowly with the hand-blower. Care is necessary at this point or else the fire will be killed by an excessive blast. As the combustion progresses add more fuel and increase the intensity of the blast. This period of preliminary blowing will usually require about twenty minutes, and the combustion products are sent out to the atmosphere. At the end of twenty minutes, turn L back to the position shown in the illustration. A valve should be placed near the engine so that the gas may be by-passed to the exhaust pipe; have this valve open and then purge out the scrubber and pipes between the engine and the producer by further blowing the producer with the hand-blower and forcing gas out through the valve just mentioned. The quality of the gas may be judged by opening the test cock and lighting the gas. If it burns with a pale blue flame the gas is not rich enough for use in the engine and the blowing must be continued. As soon as the gas burns uniformly with an orange-colored flame, the blowing may

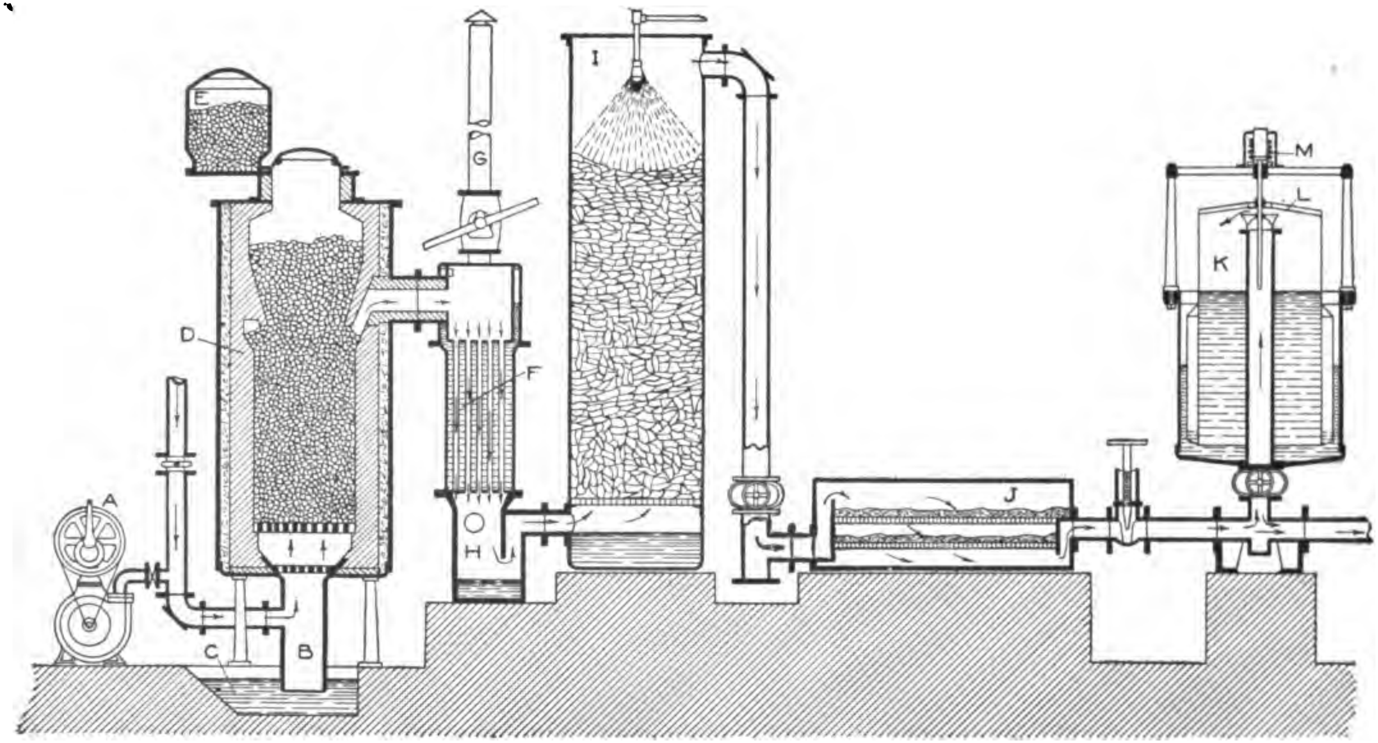


Fig. 20. American Suction Gas-Producer.

be stopped and the engine started from the producer gas. The scrubber spray must, however, be turned on before the engine is started so as to wash out the fine dust particles in the gas. In some cases it will be desirable to use the hand-blower for a few minutes after the engine has started.

The American suction gas-producer is shown in Fig. 20. A is the hand-blower. B is the ash-chamber with water-seal C. D is the body of the producer with charging hopper E. F is a tubular vaporizer above which is the vent pipe G. H is a settling chamber. The air for the producer is drawn through F, in that way absorbing the steam formed in the vaporizer, and is then taken to the ash-chamber by means of a pipe not shown in the illustration. I is an ordinary tower scrubber filled with coke and supplied at the top with a spray of water. J is a purifier; the two shelves are filled with shavings, sawdust, or some similar material; as the gas passes through this, some of the impurities are filtered out. K is an automatic regulator; it consists essentially of a tank of water containing the bell L which is supported by the spring M. The object of the device is to make the actual time of drawing gas away from the producer of longer duration than the time occupied by the gas-engine piston in charging the engine cylinder with gas. The operation is as follows: When the gas-engine piston draws gas to fill the cylinder about half will be drawn from the chamber K; as a result the exterior atmospheric pressure will cause L to move down and compress the spring M. Just as soon as the engine stops drawing gas, the spring M will draw L back of its original position, and the gas required to fill K will be drawn from the producer. In this way the process of gasification is carried on after the engine piston has filled the engine cylinder.

Any gas-producer to be operated efficiently must be supplied with the maximum amount of steam. On the other hand, no more steam must be delivered to the producer than it is able to decompose. If any excessive amount of steam is used, it will pass through the fire without being decomposed. This will chill the fire and place water-vapor in the gas. In some cases the chilling effect may be enough to stop the process of gasification. If not enough steam is used, the fire may become so hot as to make the producer very inefficient. In a suction gas-producer the quantity of gas made will be directly proportional to the load on the engine. As the latter may vary in some cases from engine friction up to full load, it is evident that the rate of gasification must also vary through a large range. As a result of the conditions just mentioned, it will be necessary to accurately proportion the amount of steam delivered to the producer to the amount of gas made therein. Several devices intended to accomplish this regulation will now be illustrated and described.

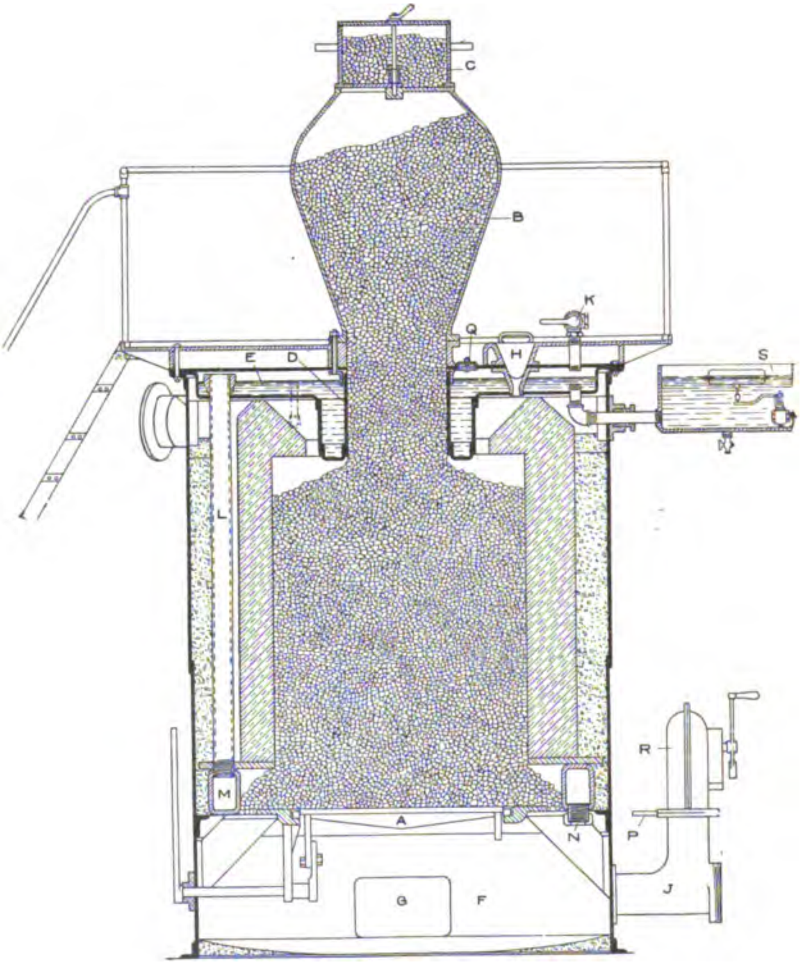


Fig. 21. American Crossley Suction Gas-Producer in Section.

The American Crossley suction gas-producer is shown in section without the scrubbers in Fig. 21, and in perspective with the scrubbers in Fig. 22. A is a shaking grate which may be operated by the lever on the outside. B is a fuel magazine with charging valve C. The fuel from B goes down through the feed tube D and into producer fuel bed below. D is surrounded by a water leg or jacket which forms a part of the vaporizer E. The construction of E is such as to form a cover for the top of the producer, and heat that is radiated upwards is used in vaporizing the water. The water in E is kept at a constant level by means of the float controlled valve in the auxiliary tank S on the side. K is an air-inlet valve. H is a poke-hole. Q is a hand-hole for removing sediment from the water leg D. L is a pipe connecting the vaporizer E with the distributing ring M. N is a nipple for allowing the air and water vapor to pass from M to ash-chamber F. G is a cleaning door for F. R is a hand-blower with valve P and delivery pipe J. The operation of the water-regulating device is as follows:

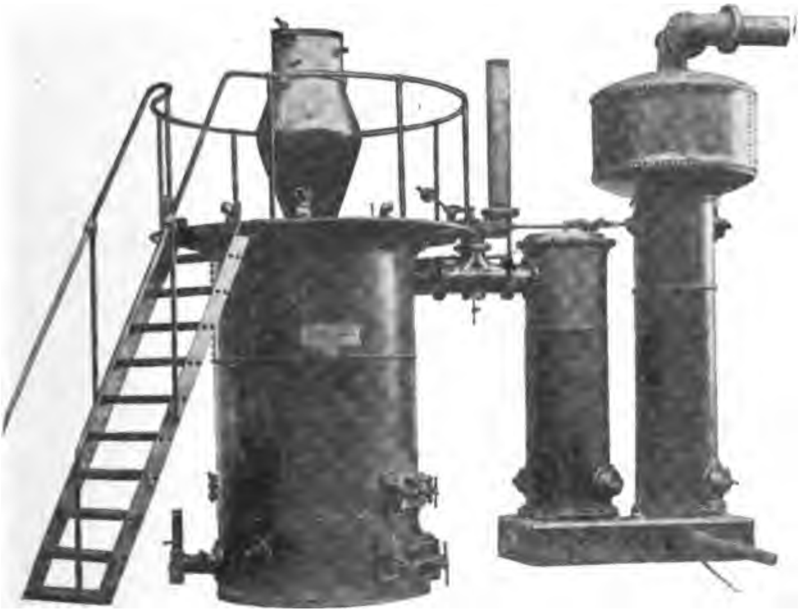


Fig. 22. American Crossley Suction Gas-Producer in Perspective.

The air for the ash-chamber is supplied from two sources. These are called the primary and secondary supply. The primary supply enters at J and passes up through the fuel bed. The secondary supply

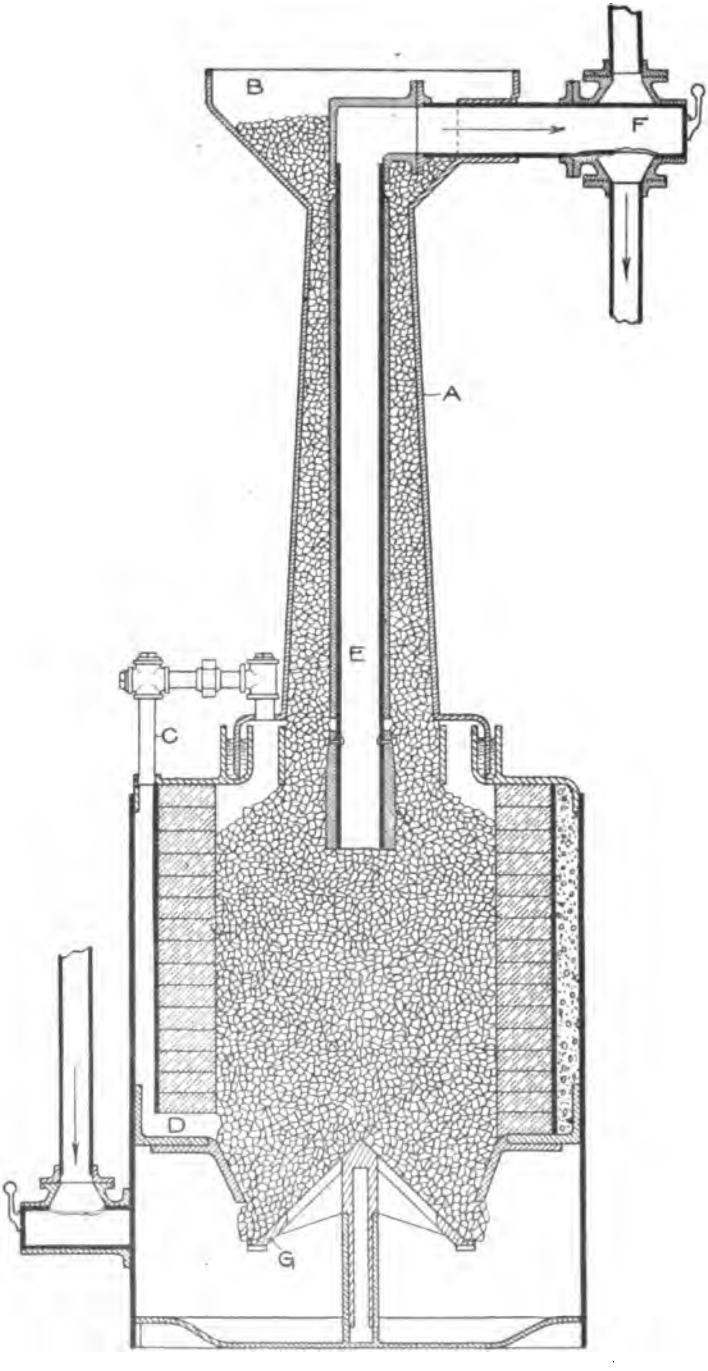


Fig. 23. Wyer Suction Gas-Producer.

enters at K, passes over the surface of the water in the vaporizer E, becoming saturated with water vapor, and then passes down pipe L into the ring M, and out into the ash-chamber F. The air entering the primary and secondary supply may be throttled by adjusting the valves P and K, so as to secure the proper proportion.

The Wyer suction gas-producer is shown in section in Fig. 23, and Fig. 24 shows its water-regulating device. Referring to Fig. 23, A is a superimposed retort with charging hopper B. The retort is connected by means of pipe C with the part D. The gas must pass around and up to the top of the retort through pipe E, and then out to valve F. In this way the gas is cooled and the fuel is preheated; that is, the sensible heat of the gas which would otherwise be lost is conserved and given back to the producers. The vapors given off in A pass to D by means of pipe C, and then go into the fire and are converted into fixed gases. G is a shaking grate which may be operated from the outside.

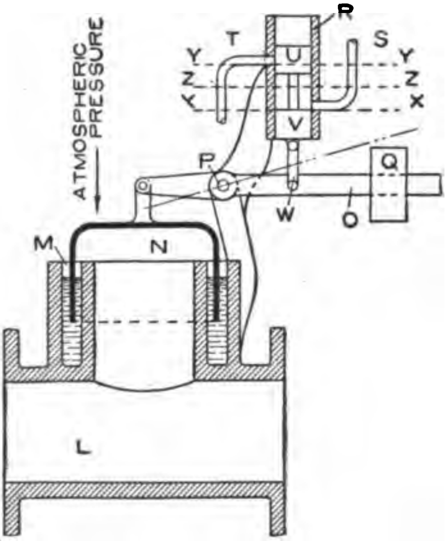


Fig. 24. Water-Regulating Device of Wyer Suction Gas-Producer.

Referring to Fig. 24, L is a pipe through which the gas passes in going from the producers to the engine; M is an annular chamber on L and is filled with water. N is a cup that is suspended in the water in M. P is a fulcrum for lever O and counter weight Q. R is a small cylinder with two pistons U and V. These pistons are connected by the small stem between them and are operated by link W and lever O. S is an inlet water port, while T is an outlet water port. From T the water goes to the vaporizer. The operation is as follows:

The weight of N is balanced by W. When the engine is drawing gas from the producer the pipe L will be at less than atmospheric pressure; as a result, the exterior atmospheric pressure on N will force it down, lift weight Q up, and move the piston V from the level X X to the level Y Y. S will be closed. T will be opened and the water contained between U and V will pass out of T and go to the vaporizer. When the engine stops drawing gas from the producer, the pressure in L increases, forces N up, closes T, and opens S. Then at the next charging stroke of the engine the same cycle is repeated. If a throttling engine is used—that is, one that proportions the amount of gas taken into the cylinder to the load on the engine—the decrease of pressure in L will be directly proportional to the gas taken into the engine cylinder, and consequently the extent of the movement of N will be directly proportional to the amount of gas used in the engine or taken from the producer. Thus, if the engine is running at half load, the movement of N will raise X X only to Z Z, and only half the amount of water contained between U and V will go out of T and to the vaporizer.

The Dowson water regulator is shown in Fig. 25. A and B are two water chambers. C is a supply pipe and D is the overflow. The height E of the water in A may be adjusted by changing the height of D in A. F is a pipe connecting A and B. G is an opening connecting B with the gas pipe going to the gas engine, so that the engine pulsations will be felt in B. H delivers the water to the vaporizer. The operation is as follows:

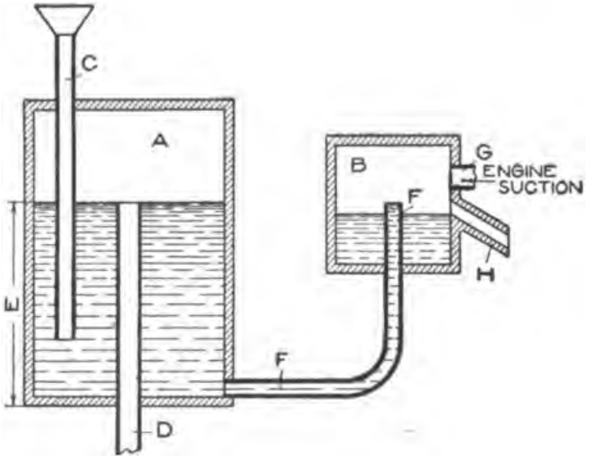


Fig. 25. Dowson Water Regulator.

During the charging stroke of the gas engine a partial vacuum will be produced in B; as a result, the water from A will flow out of the top of F, the flow ceasing just as soon as the engine has completed its charging stroke. The water so delivered to B will pass out through H. The amount of water flowing out each time may be adjusted by varying the distance E.

The Wintherthur water regulator is shown in Fig. 26. A is a chamber connected with the pipe leading from the producer to the engine. D is a piston working in A. C is an adjusting screw over coil spring D. E is a spindle with a needle valve at its lower end. F is a water chamber with overflow pipe G and inlet H. I is a pipe connecting with the vaporizer. J is a port connecting the water in F with I. K is an air inlet for the underside of the piston. The operation is as follows:

The suction action of the gas engine produces a partial vacuum in A. As a result, the atmospheric pressure on the lower side of B raises it and E, compresses D, and opens the needle valve, allowing a certain amount of water to go to the vaporizer. When the sucking action of the gas engine ceases, the spring D will force B and E down and stop the flow of water. At the next charging stroke of the engine the same cycle is repeated. The extent of the movement of E and the resulting flow of water may be adjusted by changing the compression on spring D by means of screw C.

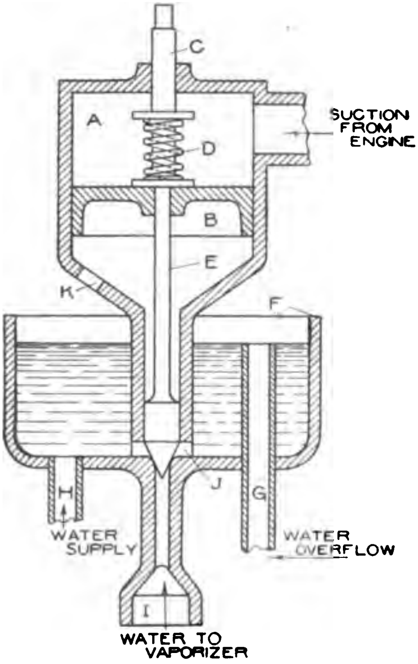


Fig. 26. Wintherthur Water Regulator.

The Pierson water regulator is shown in Fig. 27. A is a diaphragm chamber connected with the pipe leading from the producer to the engine. B is a diaphragm. C is a needle valve connected to B by link F, levers G and H, and link I. J is a counterweight. D is the water inlet from the supply and E is the water outlet. Frequently this device is used between the vaporizer and the producer so that D becomes a steam inlet and E a steam outlet. The operation is as follows:

The sucking action of the gas engine produces a partial vacuum in A and, as a result, the exterior atmospheric pressure will cause B to move inward, raise C, and allow a certain amount of water to pass through D and E. When the sucking action of the gas engine ceases, B will come back to its normal position, C will be closed, and the flow of water stopped. At the next charging stroke of the engine the same cycle is repeated. The amount of water admitted each time may be changed by adjusting the counterweight J.

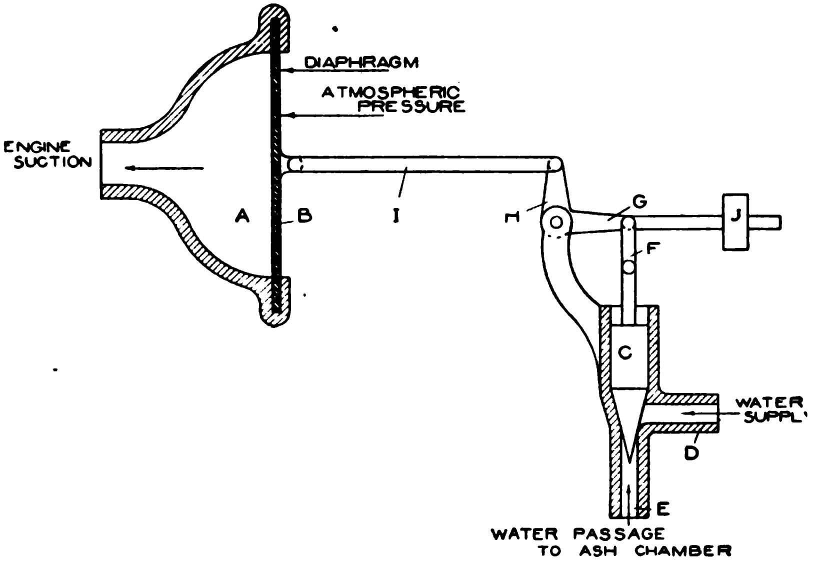


Fig. 27. Pierson Water Regulator.

The Smith water regulator is shown in Fig. 28. This also shows the heater for vaporizing the water and superheating the resulting steam and preheating the air by utilizing the waste heat in gas engine exhaust gases. A is the inlet for the exhaust gases while B is the interior of the heater. C is a thin, flat disk, around which the exhaust gases circulate and through which the air and steam pass. D is a shaft upon which the weighing vessel E is pivotally supported. F is a rod connecting E with the vane G. H is the air inlet; the curve of this is concentric with D. J is a screw for adjusting the amount of water going through the artifice I. K is the water inlet pipe, and L is the inlet valve. If more water is delivered to E than can pass out through I, the excess is drained to M by an opening not shown in the figure and then passes out through the drain N. O is a counterweight to keep E poised in the position shown in the illustration. The operation is as follows:

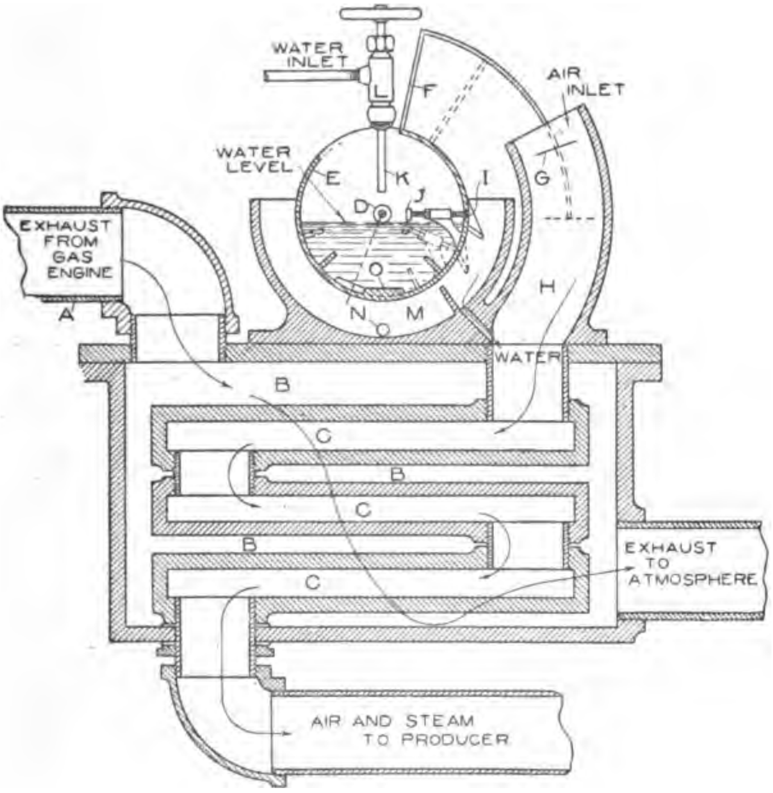


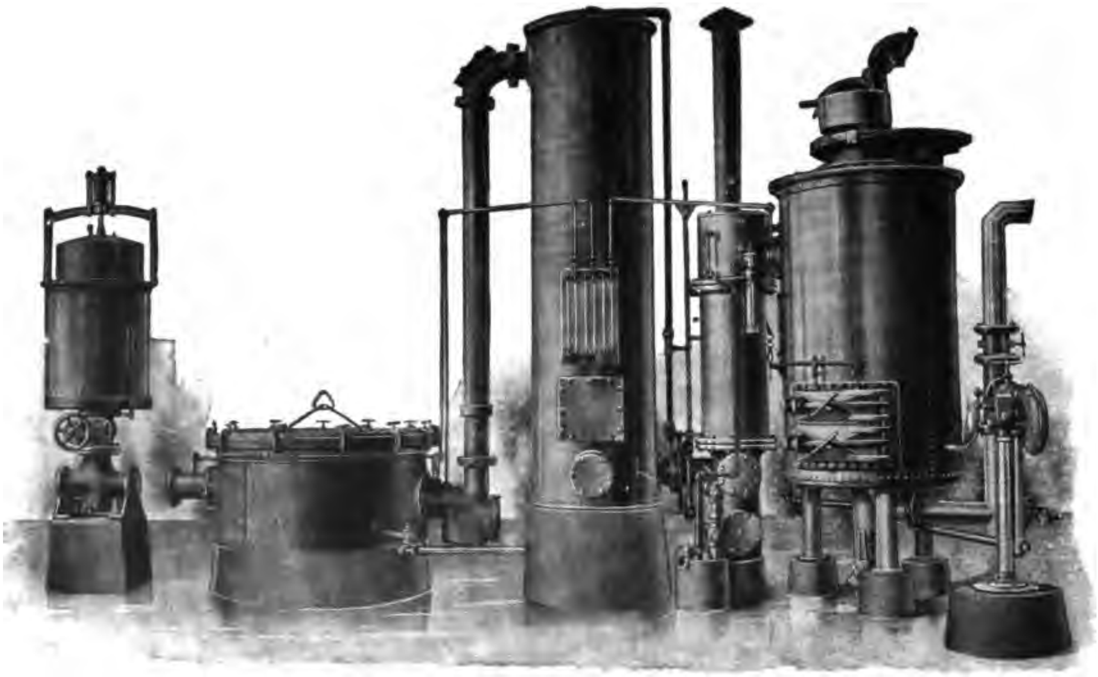
Fig. 28. Smith Water Regulator.

When the engine draws gas from the producer, outside air will rush in through H to replace the gas removed. As the air comes in past G it will cause this vane to be deflected and take the position indicated by the dotted lines; at the same time, E will be moved a corresponding amount and water will pass out of I and go down to the vaporizer below. When the sucking action of the gas engine ceases, the flow of air in H will cease and the counterweight will swing E and G back to their normal position; just as soon as I comes back to this position the flow of water will stop. The water falling down on the hot disks C is converted into steam and swept on through by the movement of the incoming air. In this passage the air becomes preheated and the steam superheated. At the next charging stroke of the engine the same cycle will be repeated. The amount of water delivered each time may be adjusted by means of the screw J.

By-product Gas-Producers. All by-product processes differ in detail only. They all are based on the same fundamental points; namely, a cooling of the gas after it leaves the producer, washing, and treatment with some reagent to precipitate the by-product.

Ammonia sulphate is about the only by-product that has enough commerical value to justify the additional expense required to save it, and its principal use is that of a fertilizer for certain soils. It is one of the most concentrated forms in which ammonia can be applied to the soil and gives very good results in clayey and loamy soils. It is, however, worthless for soils containing lime or chalk. The chief advantages of ammonia sulphate for fertilizing purposes are, that it is a definite product, quick acting, very concentrated, and easily mixed. Pure ammonia sulphate is a whitish crystaline salt and extremely soluble in water; the commercial article is generally grayish or brownish in color on account of small quantities of impurities. The ammonia sulphate is formed from the ammonia in the gas. Nearly all coal contains some nitrogen, usually about 1.5 per cent. From one-tenth to two-tenths of the nitrogen in the coal will go into the gas in the form of ammonia. By the use of an excessive amount of steam the yield of ammonia may be increased very much.

The gas-producer is usually of the pressure type and generally very little different from other producers. The by-product features are introduced after the gas leaves the producer proper. The scrubbing system must always be large and complicated; the by-product system is not adapted for small plants, and the additional first cost of the apparatus necessitates a large outlay of money. The operating expenses will also be higher on account of the salary of a skilled chemist required to handle the plant, reagents for the process and laboratory, and advertising of by-product. To make the plant



SUCTION GAS-PRODUCER PLANT
Olds Gas Power Co.

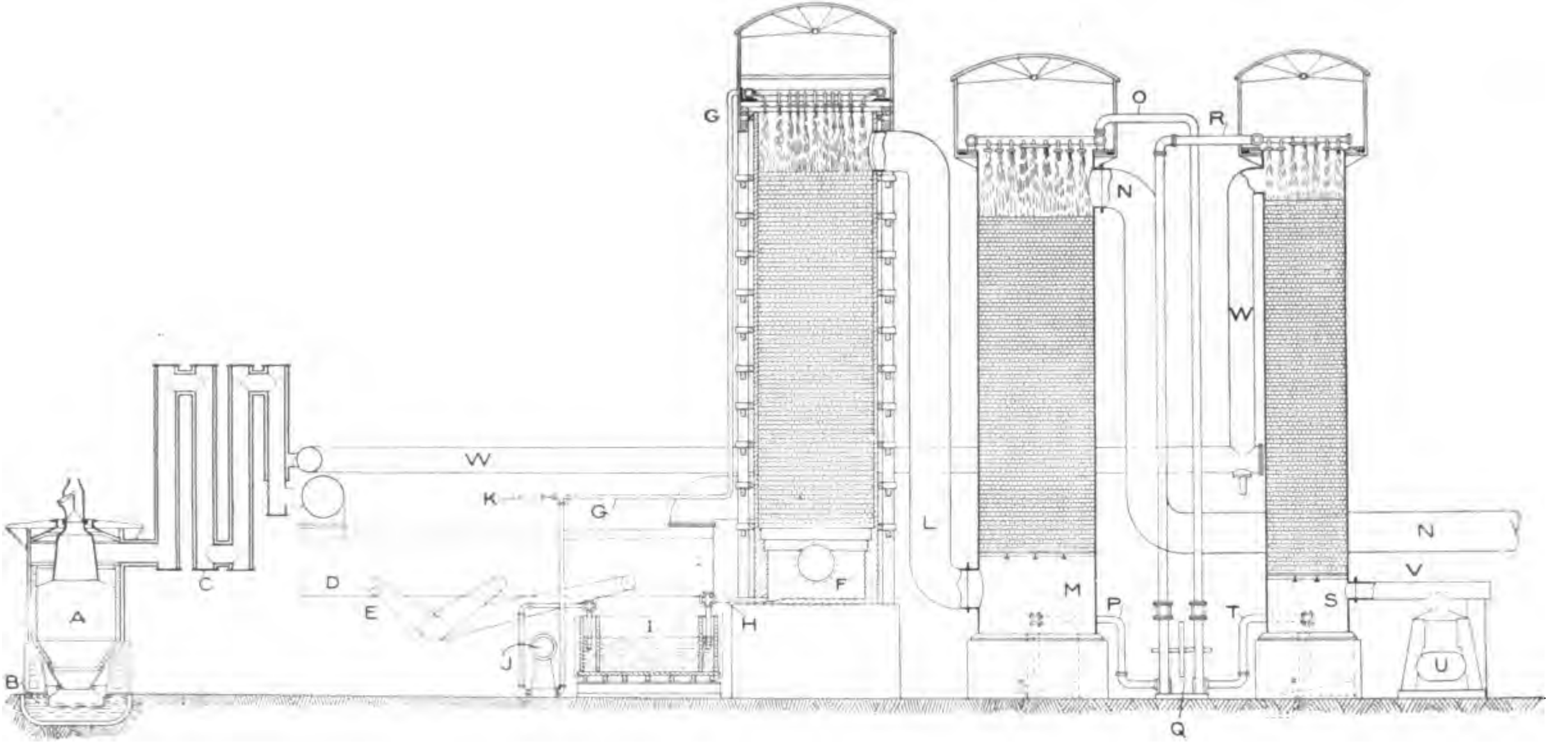


Fig. 29. Diagrammatic Section of Mond By-Product Gas-Producer.

a profitable investment the revenue from the by-product must be a considerable amount.

The Mond by-product system is the only one that has been used to any extent in this country, and it will now be described and illustrated. A diagrammatic section is shown in Fig. 29; Fig. 30 gives a general view of a Mond by-product plant, and Fig. 31 shows the producer regenerator and gas-washer. Referring to Fig. 29, A is the producer with water-seal ash-pan B. C is the air regenerator; the hot gas from the producer is passed through this and serves to preheat the incoming air, which passes through the outer compartment of the regenerator. D is a mechanical gas-washer. A few inches of water is in the bottom, and as the gas passes through, the rotating paddles, or dashers, E throw the water upward and secure a thorough mixture of the gas and water. In this way a large number of the impurities are washed out. From D the gas goes to the bottom of the acid tower F. This tower is filled with checker work and diluted sulphuric acid is introduced at top by the pipe G. As the gas goes upward, it is brought into intimate contact with the acid and this acts on the small percentage of ammonia in the gas, forming ammonia sulphate. The ammonia sulphate solution collects at the bottom of

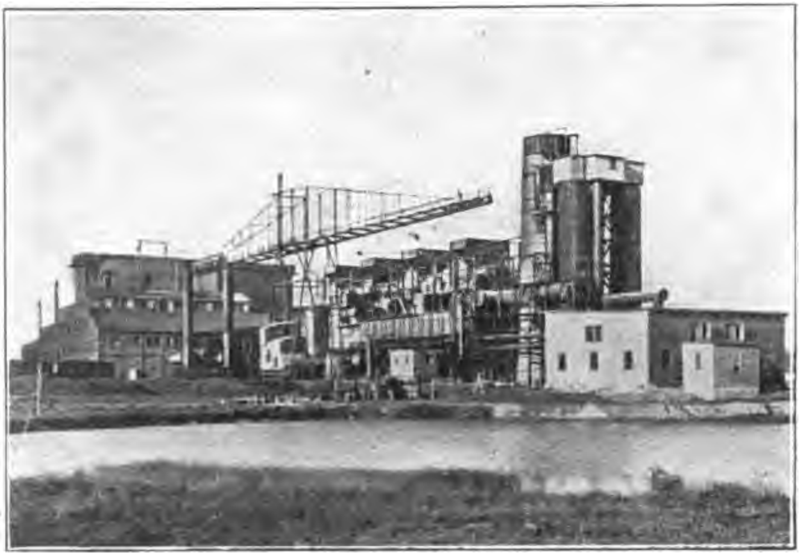


Fig. 30. General View of Mond By-Product Plant.

F and then drains to the tank I by means of pipe H. J is a circulating pump which takes the liquor from I and delivers it to the top of F by pipe G. The liquor is circulated in this way until it reaches a certain degree of saturation; then some of it is by-passed out of the system by pipe K, and a corresponding amount of fresh acid added to the tank I. The concentrated ammonia sulphate solution is then evaporated and the sulphate reduced to a solid crystaline state. From the top of tower F the gas goes to the bottom of the cooling tower M by pipe L, and then goes up and out through pipe N. O is a pipe delivering cold water to the top of M. As this water trickles down through M it becomes heated by absorbing the heat from the ascending gas. The hot water from the bottom of M is withdrawn

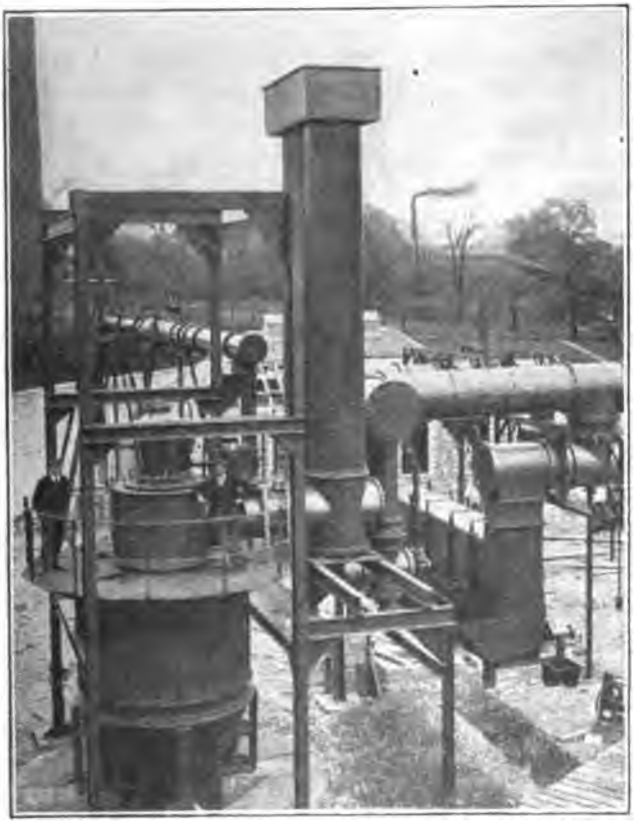


Fig. 31. Producer Regenerator and Gas Washer of Mond By-Product Plant.

by pipe P and double circulating pump Q, and then delivered to the top of the air heating tower S. U is an air blower that furnishes the air to the producer A. V is a pipe connecting U with the bottom of S. As the cold air goes up through S, it becomes heated and saturated by the hot water from R. From the top of S the air goes to the regenerator C by means of pipe W. The cold water collecting at the bottom of S is withdrawn by pipe T and the double circulating pump Q, and delivered to the top of M. From the description just given it will be seen that the water acts as a heat carrier between the gas-cooling tower M and the air-heating tower S. Some idea of the extent and size of one of these plants may be obtained by a close examination of Figs. 30 and 31.

GAS CLEANING

Producer gas, in addition to containing condensible constituents as shown in table 1, nearly always carries fine dust with it. Gas cleaning is used synonymously with gas scrubbing and gas washing and means either the removal of foreign constituents from the gas, or the removal of certain elements of the gas composition that are undesirable for certain uses of the gas. The idea of "washing" and "scrubbing" evidently comes from the fact that water is nearly always used in gas-cleaning processes. The object in cleaning any particular gas is simply to prepare it for some particular kind of work. No general rules can be laid for the number of constituents that must be removed or the degree of purity required. The primary requisite is that the gas shall be adapted to its specific work. The highest degree of purity is required for engine work; at the same time the additional cost of cleaning the gas up to that point might prohibit its use for heating a furnace where the impurities would not have a detrimental effect.

Gases may be cleaned by means of deflectors, liquid scrubbers, coolers, filters, and rotating scrubbers.

Deflectors. The deflector consists of an obstruction placed across the path of moving gas, and causes a sudden change of course. This has a tendency to precipitate the fine dust or water globules carried in suspension. It is very similar to the steam separator used near steam engines to separate the steam and water.

Liquid Scrubbers. Liquid scrubbers bring the gas in intimate contact with a liquid which is almost universally water. The liquid may be in the form of a seal, spray, or film.

Where a *seal* is used the gas is forced down into a mass of water and then bubbles up through it.

Where a *spray* is used the water is forced in a finely divided state out into a chamber and the gas is forced to pass through the spray, the object being to bring each particle of gas in close contact with a particle of water and in that way wash the impurities down into a chamber where they may be removed from time to time. The scrubbers shown in connection with the suction gas-producers, previously described, are of this type.

Where a *film* is used the stream of water is divided into as thin a film as possible and the gas is then zig-zaged across this a number of times.

Cooler. The cooler simply lowers the temperature of the gases passing through it, and in that way causes the condensible constituents to be precipitated. They are frequently used for removing the moisture or water vapor carried by producer gas made from wood.

Filter. The filter consists of some porous material through which the gas is passed and in so doing deposits some of its impurities in the filtering material. Shavings, excelsior, and sawdust are the filtering materials most generally used. Just as soon as the filtering material becomes saturated with impurities its usefulness as a remover of foreign matter from the gas ceases.

Rotating Scrubbers. Rotating scrubbers may be divided into two classes; those which are intended only to secure a thorough mixing action between the gas and some liquid, which is usually water; and those which drive the impurities out by centrifugal force. The former operate at comparatively slow speed, while the latter must be operated at a high speed in order to secure the centrifugal separation. The high speed type depends on the fact that all the impurities in the gas are heavier than the gas itself; as a consequence, when a mass of gas is rotated at a high speed the impurities will be driven out to the periphery of the apparatus.

It is very seldom that one type of gas-cleaning apparatus is used alone, but two or more types are frequently used together. In suction-producer gas plants deflectors, sprays, and seals are frequently used together. No one type is usually efficient enough to remove all the impurities.

The removal of *tar* from gas is one of the hardest problems in connection with gas cleaning. The use of a tar-laden gas in gas engines will quickly gum the valves and necessitate a stoppage of the producer and engine. This is the reason why so many gas-producers for power purposes are using anthracite coal. This particular fuel making a gas practically free from tar, makes the problem of gas cleaning an easy matter. However, there are many cases where the high cost of anthracite coal prohibits the use of producer gas for power purposes. In many instances the cost of anthracite coal is four times the cost of bituminous coal. Now, since a pound of the latter will make just as much producer gas as a pound of the former there would evidently be a decided advantage in many cases to use bituminous coal in a producer-gas power plant. The problem of the use of bituminous coal for such work is simply the problem of eliminating the tar. This may be done by the separation of the tar from the gas or the use of a device that will prevent the formation of the tar or its deposition in the gas.

Tar is a very complex substance and is one of the products of the destructive distillation of coal. It is made up of about two hundred other compounds and some of these are so complex and hard to isolate that very little is known about them. The exact composition will depend on a large number of factors, the most important of which is the temperature at which it is formed. Coal tar has a specific gravity of about 1.15, a black color, and a very marked and disagreeable odor. It condenses easily and if brought into intimate contact with incandescent carbon it may be converted into fixed gases. The last fact just mentioned forms the basis of all tar-destruction methods; that is, where the tar is broken up in the producer.

The separation of the tar from the gas may be accomplished by an extensive tower scrubber or the use of some form of centrifugal apparatus which will drive the tar out of the gas by centrifugal force. The latter method can be made very effective, but the former is adapted only for gas containing small amounts of tar. On the other hand, the centrifugal method requires close watching, and, in some cases, considerable power to run the apparatus; neither method is as satisfactory as the complete destruction of the tar in the producer.

The tar is always evolved in the distillation zone and goes directly into the distillation products. All schemes for tar destruction consist in bringing these *distillation* products into close contact with hot carbon, so that the condensible constituents will be converted into fixed gases. This may be accomplished by the use of a down-draft producer, as shown in Fig. 16; the removal of the gas in the middle of the producer or the circulation of distillation products, as shown in Fig. 15; the use of a distillation retort, as shown in Fig. 14; or underfeeding, as shown in Fig. 18. The passing of the tar through a separate chamber filled with incandescent coke has also been used.

USES OF PRODUCER GAS

The use of producer gas now extends to a large number of industries. The following diagram taken from the author's Treatise on Producer Gas and Gas-Producers gives a classification of the various uses.

GENERAL USES OF PRODUCER GAS.

- 1. Fuel for Gas Engines
- 2. Firing Steam Boilers
- 3. Firing Ceramic Kilns
  - Brick Kilns
  - Tile Kilns
  - Pottery Kilns
  - Muffle Kilns
  - Lime Kilns
  - Cement Kilns
- 4. Firing Metallurgical Furnaces
  - Forges
  - Steel Furnaces
  - Muffle Furnaces
  - Glass Furnaces
  - Roasting Furnaces

PRODUCER-GAS POWER PLANTS

There are now a large number of producer-gas power plants in successful operation in America. They have many advantages over steam plants and many more will be installed in the future. To be successful, the gas-producer and gas engine must be adapted to each other. Producer gas having a lower calorific power, the engine must handle a large volume of gas, and, as a result, the ports and valves must be larger. A 100-H. P. gas engine designed to use natural gas will develop only about 80-H. P. with producer gas or a loss of

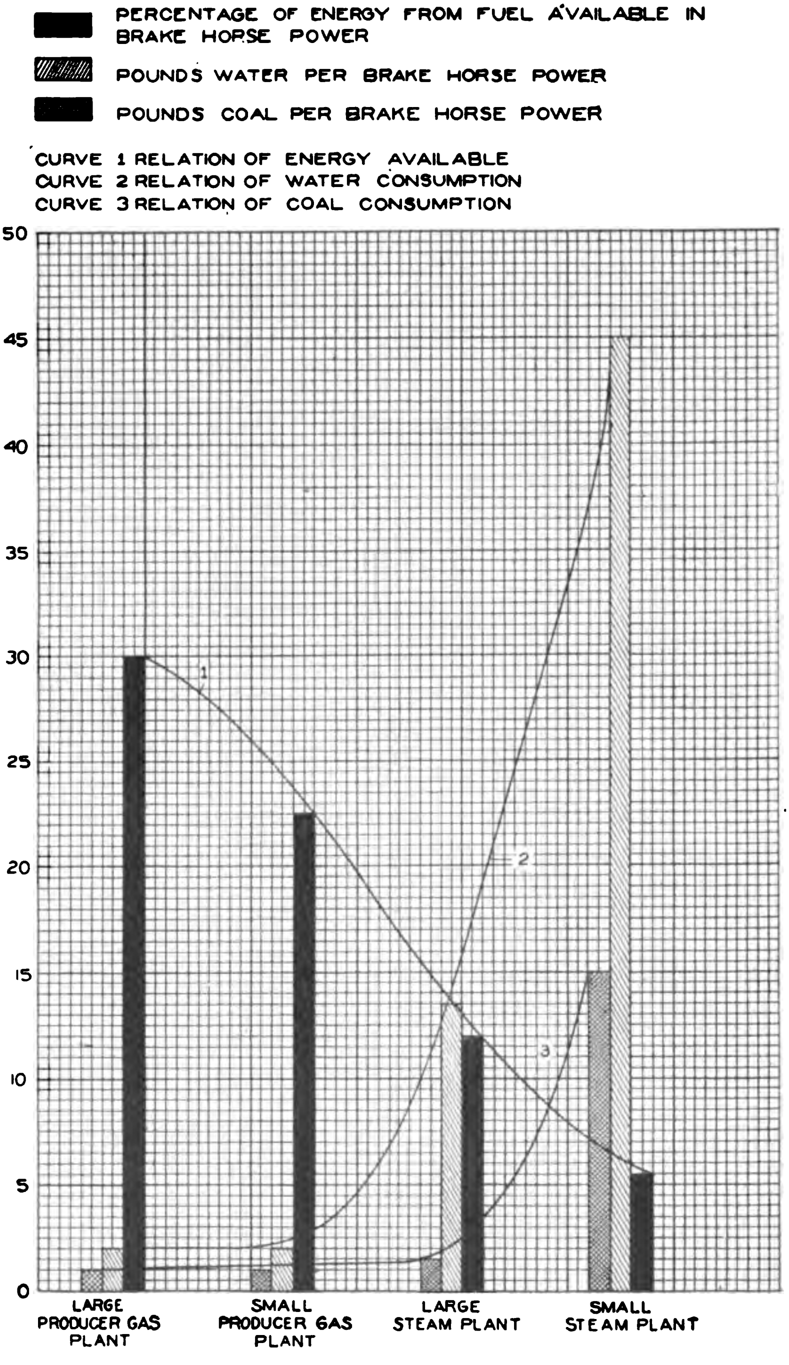


Fig. 32. Chart Showing Relative Efficiency of Producer-Gas and Steam Power Plants.

about 20 per cent. If a suction gas-producer is used there will be a further loss of probably 4 per cent due to the negative work of drawing the gas away from the producer.

The high fuel and water economy of the producer-gas power plant is one of its strongest advantages over the steam power plant. These points are clearly shown in Fig. 32. This arrangement of data brings out several important points. It will be seen that there is little difference in the coal or water consumption between large and small producer-gas plants. This is due to the fact that small gas engines may have practically the same thermal efficiency as large ones. As a result of this fact the small producer-gas power plant can be operated nearly as cheaply as a large plant. In other words, it is not necessary to use large units in order to get economical results. In many cases where the load fluctuation is large much better results will be obtained by installing, say four 500-H. P. gas engine units in place of one 2,000-H. P. unit. Another interesting fact shown on Fig. 32 is, that even a small producer-gas plant is more economical than a large and complicated steam plant. The economy of water of the producer-gas plant over the steam plant is always a desirable feature for the former, and in cases where water is scarce or impure so as to make it undesirable for boiler use, it is of the greatest importance.

Inasmuch as the gas-producer does not make any smoke, it is evident that the producer-gas power plant offers an ideal solution for the smoke problem. Just as soon as public sentiment against the smoke nuisance becomes crystalized into prohibitory laws, the gas-producer industry will receive a new impetus.

The labor in a producer-gas plant will generally be about the same as that in a similar steam plant. It is, however, much easier to install mechanical appliances for handling the fuel in a gas plant than in a steam plant. If a suction gas-producer is used the labor will also be decreased. The producer may be started in about twenty minutes and can be stopped instantly.

The first cost and cost of repairs will be about the same in producer-gas as in steam plants. Gas engines cost more per horse power than steam engines, but the cost of the smoke stack is eliminated. Sometimes in small producer-gas plants the cost will be about one-fifth higher than in steam plants.

In steam and producer-gas plant the steam and producer gas simply act as carriers of thermal energy. The cooling of the steam will lower and may entirely destroy its thermal energy, while the cooling of the gas will simply decrease its volume and increase the thermal energy carried per cubic foot. This last statement refers to calorific power only; since the sensible heat of the gas is of no use in the gas engine, the temperature of the gas as it leaves the producer should be very low. In other words, with producer gas the thermal energy carried by the gas *for* the gas engine will *not* be lowered if the gas is cooled. This fact makes it possible to put in central producer-gas plants with long pipe lines to distribute the gas to isolated engines.

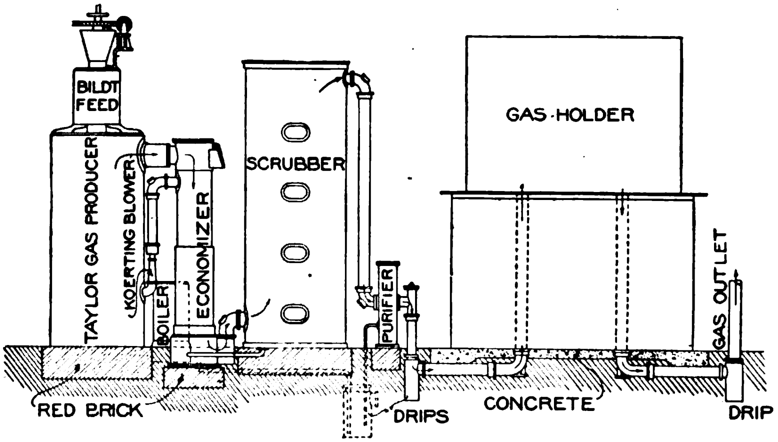


Fig. 33. Typical Producer Plant—Pressure Type.

This would mean a large saving in shafting, especially when electrical power is not available. Then too, it is entirely possible to build a large producer-gas plant at the coal mines and in place of shipping the coal to the various places of consumption simply pipe the gas to those places. This scheme if properly executed will give much better results than the shipping of coal to a large number of small plants.

The use of a gas holder for storing the gas has marked advantages in certain cases. By this means irregularities in the load may be taken care of without any difficulty. In some industries it may be desirable to have a small amount of gaseous fuel for heating furnaces, as forges, and, in such cases, the gas may be taken from the same holder that supplies the engine.

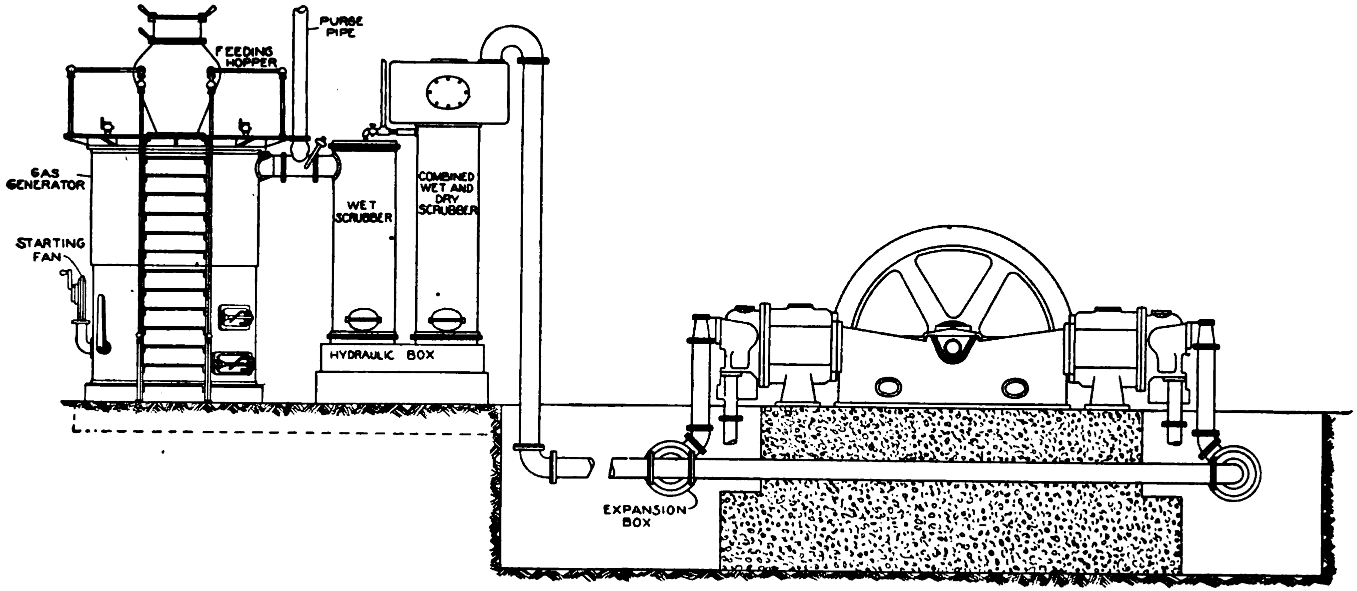


Fig. 34. Typical Suction Producer-Gas Power Plant.

Fig. 33 shows a typical producer-gas plant. The names of the various parts are given on the illustration. The holder is frequently placed farther away from the producer than shown in the illustration; in fact, it may be placed on any area that is available, regardless of immediate proximity to the producer. Fig. 34 represents a typical suction producer-gas power plant. The engine shown at the right-hand side and the names of the other parts are clearly indicated on the illustration. Fig. 35 is another view made from a photograph of the previous plant. The engines are shown in the foreground, while the producer and scrubbers may be seen beyond the open doorway. In Figs. 33 and 34 all the parts are shown in line with one another. This is done only to simplify the illustration. In nearly all installations the producer and auxiliary apparatus is arranged in more compact form.

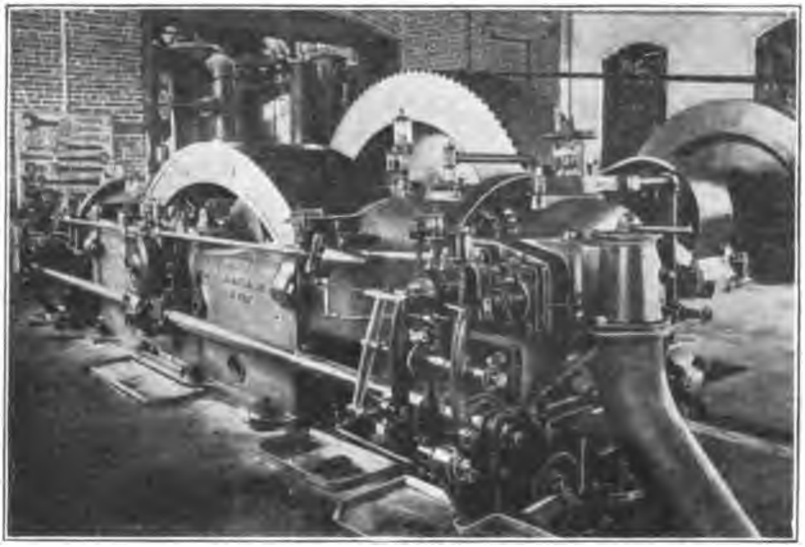


Fig. 35. View of Engine and Producer Room of Suction Producer-Gas Power Plant.

Firing Steam Boilers. Producer gas has been used to a limited extent for this work in Europe. It is not very good engineering practice and should be used only in cases where steam is required in the process of manufacture; as for instance, in steaming lumber. It will be much better to eliminate the boiler entirely in other cases and use the gas directly in a gas engine. In general, no direct fuel economy will result from first gasifying the fuel in a gas-producer and then burning the resulting gas under a steam boiler.

Firing Ceramic Kilns. Producer gas has been used extensively in Europe for this work but until the last few years has had a very limited use in America. Several costly failures have been made in attempting to use it, but these have not been the fault of the system but rather were due entirely to the ignorance of the men who have attempted to use it. Producer gas has decided advantages for ceramic work, but great care is necessary in applying it. No generalized rules can be given for its application. Every installation must be studied in detail and all the results co-ordinated to each other in order to secure a harmonious unit. The best results will be obtained in connection with continuous kilns. The use of producer gas in kilns eliminates clinkering in the kilns, induces more uniform burning, produces better combustion, makes it possible to regulate fire more readily, secures a centralization of furnaces, and should result in fuel economy.

Firing Metallurgical Furnaces. This was the first, and even today, is the largest field for the use of producer gas. It has been an important factor in developing the modern steel industry and has become a commerically necessary adjunct of it. The types of producers shown in Figs. 5, 6, 7, 8, are used very extensively for this work.

REQUIREMENTS

One of the most important requirements is that the gas-producer shall be adapted to the work it has to do. The construction of the producer should be compact and simple and so designed as to permit the easy removal of worn out parts. The feeding device should be such as to secure a uniform distribution of the fuel. The blast should be so introduced as to burn out all the carbon in the ash-zone and yet not produce localized combustion along the walls. The construction should be such as to permit the easy removal of the ashes. The entire process of gasification should be clean. The radiation loss should be low, and the producer must be efficient.

GAS POISONING

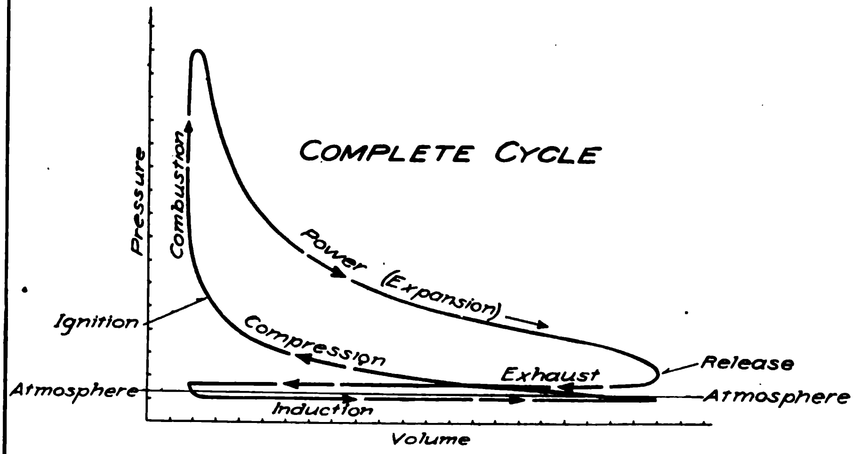
Producer gas on account of the presence of carbon monoxide will always be poisonous. The carbon monoxide has a specific toxic effect on the human system, and when inspired enters into direct combination with the blood. The new compound formed is incapable of carrying oxygen to the tissues and is so stable that it can be broken up only with great difficulty. The action is very insidious, and if the amount that is inhaled is small, the person breathing it may be made almost helpless before they are aware of it. The symptoms are a sense of discomfort, with throbbing of the blood vessels, severe headaches, giddiness, and great debility. In case of poisoning, the first thing is to remove the patient to the fresh air and send for a physician. In handling a patient, great care must be exercised to keep the head higher than the lower part of the body.

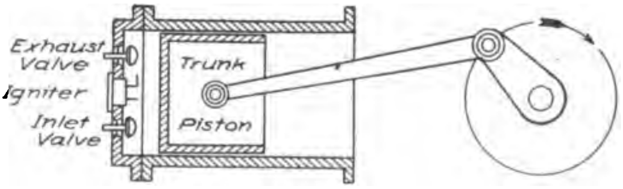
CONCLUSIONS

The manufacture of producer gas is an old and well-established process. The process is not complicated and the chemical reactions are simple. Originally developed as a by-product of the iron industry, its ramifications now extend to a large number of industries. In many cases its use will result in fuel economy, and in the near future producer-gas power plants will be as common as steam power plants.

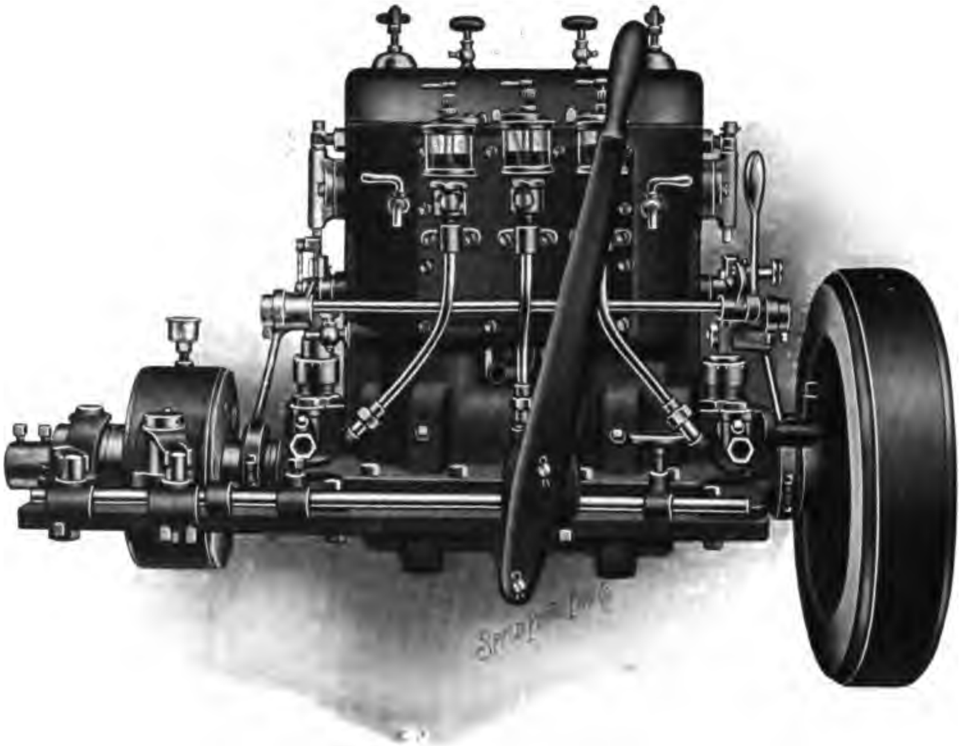
DIAGRAM SHOWING OPERATIONS OF THE FOUR STROKE CYCLE

(Lower part of diagram near atmosphere exaggerated)





1st CYCLE	**POWER**	→	1st STROKE	1st Revolution
	Exhaust	←	2nd "	
	Induction	→	3rd "	2nd Revolution
	Compression	←	4th "	
2nd CYCLE	**POWER**	→	5th STROKE	3rd Revolution
	Exhaust	←	6th "	
	Induction	→	7th "	4th Revolution
	Compression	←	8th "	



TOQUET MARINE MOTOR.
Starboard Side with Reverse Gear.

GAS AND OIL ENGINES.

The heat engine is at present the most important of all the available generators of power. Its purpose is to convert the heat of combustion of some fuel into work. Existing heat engines may be divided into two classes, according to where the combustion of the fuel takes place. In one class the combustion takes place entirely outside the working cylinder, and the heat of combustion is transmitted by conduction through the walls of a containing vessel to the substance which does the work. Such engines may be called *external combustion motors*. The most common example of this class is the steam engine; another example, which is but little used, is the hot-air engine. If the combustion takes place inside the engine itself, or in a communicating vessel, so that the products of combustion act directly on the engine, we have an engine of the second class—the so-called *internal combustion motors*. Gas and oil engines are the common examples of this type of motor.

THE EXTERNAL COMBUSTION MOTOR.

Engines of the second class have certain inherent advantages over external combustion motors. In the steam engine, practically the most perfect of the external combustion motors, the heat of combustion which is generated in the furnace passes through the plates of the boiler to the water on the other side. During this process about twenty-five per cent of the heat is wasted by radiation and by loss up the chimney in good modern plants. The water in the boiler is heated to a temperature which does not exceed 400° F. because at that temperature it has a pressure of nearly 250 lb. per square inch. If the water were heated to a much higher temperature, the pressure would be too great (for example, at 500° F. the pressure would be 700 lb.), requiring boilers and engines stronger than are at present practicable. The products of combustion in the furnace have a temperature which is seldom less than 2,000° F. There is consequently a very large necessary drop of temperature as the heat passes through the boiler plates. The proportion of the total heat going to an engine that can be converted by the engine into work depends chiefly upon the temperature range of the working substance, and in the steam engine this range is made comparatively small—not exceeding 300° F.—because of the corresponding pressure limits. Consequently a steam plant not only loses much of its heat up the chimney, but also is able to convert but a small part of the heat that goes to the engine into work. In the best modern steam engines about twenty per cent. of the heat going to the engine is converted into work, and about sixteen per cent. of the heat of combustion of the fuel is converted into work in the best modern steam plants. The ordinary steam engine does not convert into work more than from six to ten per cent. of the heat of combustion of the fuel. An economical steam plant consists not cnly of boilers and engines, but also has a large number of auxiliaries, such as feed pumps, air pumps, condensers, feed water heaters, economizer, coal conveyers and steam traps. It requires considerable time and fuel to raise steam in the boilers before the plant can be put in operation after shutting down; or, if the fires are kept banked, so as to keep up steam pressure while the engines are not running, a not inconsiderable amount of fuel will be used for this purpose, without any corresponding work being done.

THE INTERNAL COMBUSTION MOTOR.

In the internal combustion motor where the fuel is a gas or volatile oil, there is no apparatus corresponding to a boiler and no losses corresponding to the boiler losses. If the fuel is coal, it has to be converted into gas before it can be used in an internal combustion motor, and thus necessitates the use of a gas producer in which some heat will be lost, though not so much as is usual in a boiler. The fuel being burned in the engine gives there a temperature of from 2,000° F. to 3,000° F., so that the temperature range in the engine is very large, and consequently the engine can be more efficient—that is, can convert a larger proportion of the heat of combustion into work than in a steam plant. The high temperatures are not necessarily accompanied by high pressures because it is air and not water which is heated to that temperature. In practice the best internal combustion motors have converted thirty-five per cent. of the heat of combustion into work, or twice as much as the best steam engines, and the ordinary small gas engine will convert from fifteen to twenty per cent. of the heat of combustion into work. The internal combustion plant is also much simpler, having but few auxiliaries. The number of men necessary to run a large gas engine plant is small, the plant is ready to start up at a minute's notice, and the standing losses are very small or nothing. When a liquid fuel is used, the absence of boiler or other auxiliaries makes the internal combustion motor lighter, more compact, and more easily portable than any other motor. The absence of a boiler also does away with the risk of a disastrous explosion, and consequently there is no inspection required by law, no license for running the plant, and lower rates for insurance. The internal combustion motor is comparatively recent in its practical use. The last five years have brought about great improvements in its operation, a big increase in its use and large extension in its application. The internal combustion motor is less uniform in its speed of rotation, and is more liable to derangements than the steam engine, but these difficulties are rapidly being overcome, so that modern gas engines are used for electric lighting and have a reliability but little short of that of the steam engine.

The fuels that are used in external combustion motors may be solid, liquid or gaseous. In internal combustion motors, though, theoretically, the fuel may be in any of these three forms, the solid fuels are not practicable because the incombustible matter or ash present in them would rapidly destroy the rubbing surfaces in the cylinders. The actual fuels used are either gaseous or liquid, and the latter may be sent into the cylinder either as a vapor or as a liquid. There is no essential difference between engines using gas and those using oil; the cycle of operations occurring in the cylinder is the same with both kinds of fuel; the only differences are slight structural differences, with the addition of special apparatus for vaporizing the oil. The same engine can be, and often is, converted from a gas to an oil engine by merely changing valves.

In this paper whatever there is of thermodynamic theory applies to both gas and oil engines. The special features of oil engines are treated after the discussion of the gas engine.

HISTORY OF THE INTERNAL COMBUSTION MOTOR.

The history of the internal combustion motor begins with the invention of cannon. A gun is a motor in which the working substance is the gas resulting from the combustion of the powder and in which work is done on the projectile, giving it kinetic energy. Such a motor is not continuous in its action, but it offers possibilities of a practicable engine if the powder charge is small and the projectile or piston on which the gases act is restricted in its movement. The earliest internal combustion motors devised for doing useful work were intended to use gunpowder. The first of these was suggested by Abbé Hautefeuille in 1678, and was followed shortly by others, none of which were practically realizable in the then state of the mechanic arts.

It was not till the discovery by Murdock, near the end of the eighteenth century, that a combustible gas could be obtained from coal by a process of distillation, that a practical internal combustion motor was possible. As soon as the properties and method of manufacture of coal gas became known, numerous attempts were made to use it in engines. Until the year 1860 many engines were devised, patented, and in several cases constructed, operated and sold. None of these engines can be said to have been satisfactory. They were irregular in action, noisy, wasteful of fuel, and generally had practical defects.

The Lenoir Engine, which appeared in 1860, was the first really practical gas engine. Hundreds of these engines were made and sold, and the greatest interest in this type was aroused in France, where it was built, and in England, where it was largely used.

In general appearance the engine resembles a double-acting horizontal steam engine. The cylinder, shown in horizontal section in Fig. 1, has a separate admission port *a* and exhaust port *b* at each end. The valves are simple slide valves driven by eccentrics, and so designed that the inside edges alone uncover the ports. The valve G is used for the admission of the explosive mixture, which consists of air entering the valve cavity from *d* and gas coming through one of the branches *r* of the gas pipe and passing through the hole *i* in the valve. The air and gas enter the port *a* through a number of small holes in which they are thoroughly mixed, and the mixture is exploded in the cylinder, when desired, by an electric igniter *n*. The exhaust is through the port *b* and the cavity in the exhaust valve H to the atmosphere. As the cylinder rapidly becomes very hot, it is provided with a water jacket.

The series or cycle of operations which takes place in this engine is as follows: During the first part of the stroke the admission valve G uncovers the port *a* so that a mixture of air and gas enters the cylinder, filling the space behind the piston. At half stroke the valve closes the port and a spark from an induction coil passes between the terminals *n* of the electric igniter, exploding the mixture and raising its pressure to 60 or 70 lb. per square inch. The piston is then forced to the end of its stroke, the products of combustion expanding behind it. At the end of the stroke the valve H uncovers the exhaust port and keeps it open throughout the whole of the return stroke so that all the products of combustion are expelled to the atmosphere. A similar cycle of operations occurs on the other side of the piston. In Fig. 1 the valve G is just opening the port at the left so that admission may

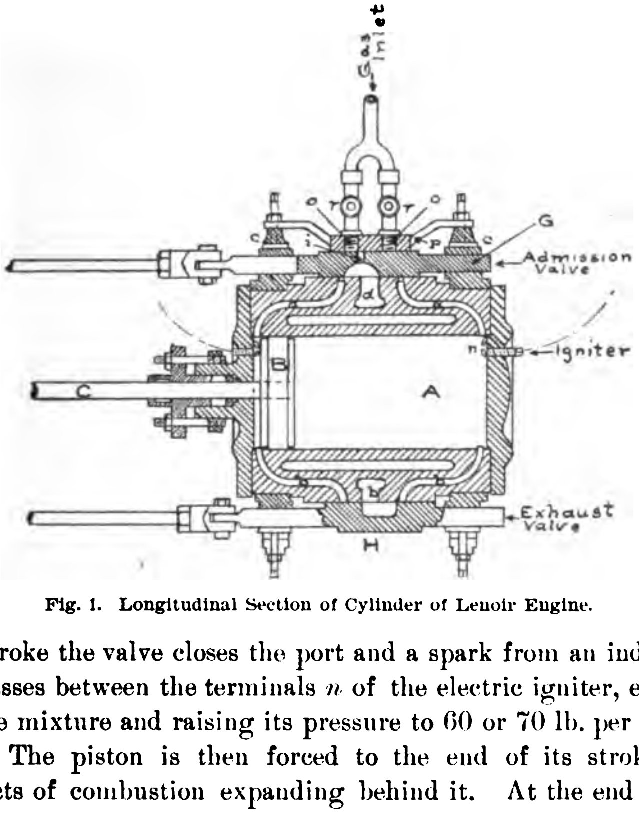


Fig. 1. Longitudinal Section of Cylinder of Lenoir Engine.

take place there, and the valve H is just opening the port at the right so that exhaust may occur from the other end of the cylinder. A reproduction of an indicator card from this engine is shown in Fig. 2.

This engine gave considerable trouble in many cases, but the principal reason for the falling off in its use was the large amount of gas it required. It used from 60 to 70 cubic feet of coal-gas per I. H. P. per hour, or from three to four times as much as a modern gas engine, so that it did not compare very favorably with the steam engine in its running costs.

The Otto Cycle. In the year 1862 it was pointed out by a French engineer, Beau de Rochas, that in order to get high economy in a gas engine certain conditions of operation were necessary. The most important of these conditions is that the explosive mixture should be compressed to a high pressure before ignition. In order to accomplish this he proposed that the cycle of operations should occupy four strokes or two complete revolutions of the engine, and that the operations should be as follows:

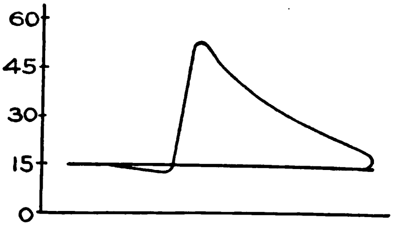


Fig. 2. Indicator Card of Lenoir Engine.

1. *Suction* or *admission* of the charge of gas and air throughout the complete forward stroke.

2. *Compression* of the explosive mixture during the whole of the return stroke so that it finally occupies only the clearance space.

3. *Ignition* of the charge at the end of the second stroke and *expansion* of the exploded mixture throughout the whole of the next forward stroke.

4. *Exhaust* beginning at the end of the forward stroke and continuing throughout the whole of the last return stroke.

This cycle was not actually used till 1876, when Dr. Otto adopted it in his engine and thereby produced the modern gas engine. The four-stroke cycle of Beau de Rochas is now universally known as the *Otto cycle*. In the past twenty years several other cycles, some of great merit, have been devised and used, but at the present day an overwhelming majority of the existing internal combustion motors use the Otto cycle. The engines using this cycle are accordingly treated of first and at greatest length.

THE MODERN GAS ENGINE.

The construction of a modern gas engine using the Otto cycle is illustrated in the sectional elevation, Fig. 3, of a vertical engine. As in practically all Otto cycle engines, the engine is single-acting and has a long trunk piston which acts as a crosshead and also permits the use of several piston rings by which leakage past the piston is prevented even with the high pressure obtained by the explosion. The engine is made single-acting because the cylinder would get too hot for continuous running if it were double-acting; and moreover, a piston rod and stuffing box give great trouble if exposed to the high temperature of the burning gases. Since the cycle occupies two revolutions, the valves and igniter have to operate once in two revolutions, and therefore the cams which drive these parts are mounted on shafts running only half as fast as the main shaft.

Referring to Fig. 3, A is the shaft which carries the exhaust valve cam, and is driven by gears from the main shaft. The exhaust cam works against a roller carried on the free end of the guide lever G. The exhaust valve E has a long stem projecting downward and resting on a hardened steel plate on the upper side of the guide lever G. The spring surrounding the stem serves to bring the exhaust valve back to its seat and to keep the stem in contact with the guide lever. From the exhaust cam shaft A a horizontal shaft with bevel gears leads to the opposite side of the engine, engaging with a vertical shaft which in turn drives the upper cam shaft B. Incidentally, the vertical shaft carries the governor. The upper cam shaft carries two cams. One engages against a roller on the end of the horizontal lever C. As the throw side of this cam comes uppermost, the opposite end of the lever C depresses the stem of the inlet valve J, opening the latter for the admission of the mixture of gas and air. A spring on the stem of the inlet valve furnishes a means for closing it and keeping the cam and roller always in contact with each other. Immediately adjacent to the inlet valve cam is the igniter cam, which at the proper instant operates a horizontal plunger working through the guide D to break the electric current through the wire S at the terminals of the igniter F.

The cylinder heads and the upper end of the cylinder are thoroughly water-jacketed, as, owing to the extreme heat to which

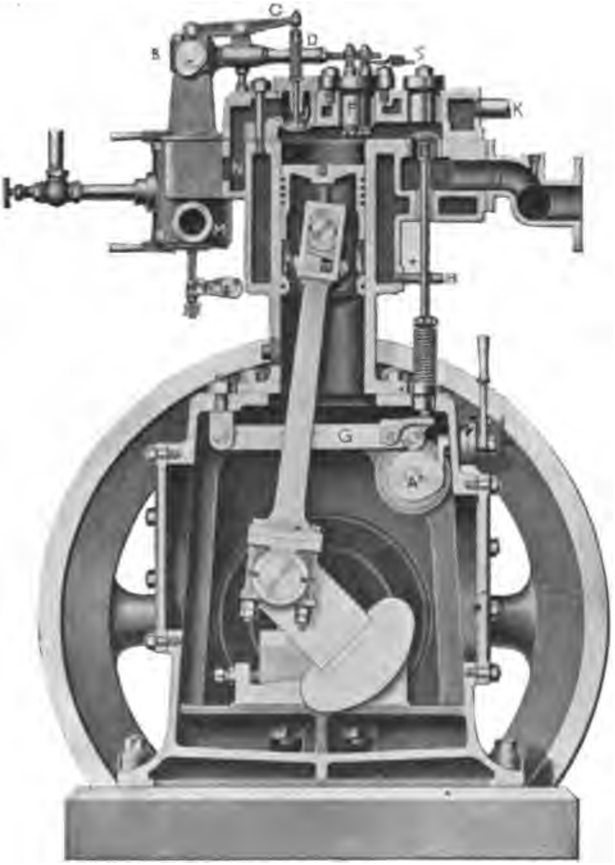


Fig. 3. Westinghouse Gas Engine.

these parts are subjected, they would soon become red-hot if no means were provided for keeping the temperature down. The cooling water enters at H and is discharged at K.

The gas and air enter the mixing chamber M by separate inlets, in proportionate amounts which can be regulated, and the mixture is conducted through a distributing chamber to the port

N leading to the cylinder head in which the inlet valve is located. The exhaust gases escape through O.

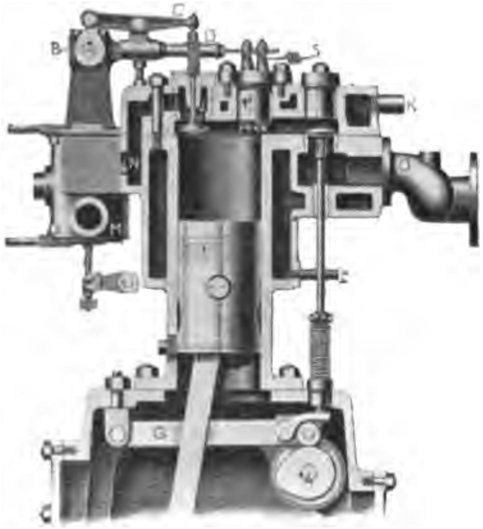


Fig. 4. Admission of the Charge.

The operation of this engine is illustrated in the accompanying illustrations. The admission of the charge of air and gas takes place during the first downward stroke of the engine (Fig. 4). The exhaust valve E is closed and the admission valve J is open, and closes only when the piston is at the end of the stroke and the cylinder is full of the explosive mixture. During the return stroke (Fig. 5) both valves are closed and the charge is compressed till at the end of the stroke it occupies only the clearance space. Shortly before the end of the stroke the igniter cam has brought the igniter terminals into contact, completing an electric circuit. When the crank is nearly on its dead center the igniter terminals are separated by the action of a coiled spring in the guide D, and as they fly apart the circuit is broken and a spark passes between the terminals (Fig. 6), igniting the charge. An immediate

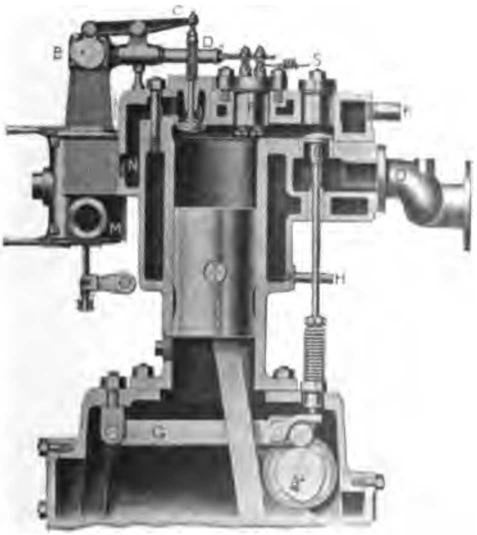


Fig. 5. Compression.

rise of pressure occurs and the piston is forced downward, both valves remaining closed until just before the end of the down stroke, when the exhaust valve E opens.

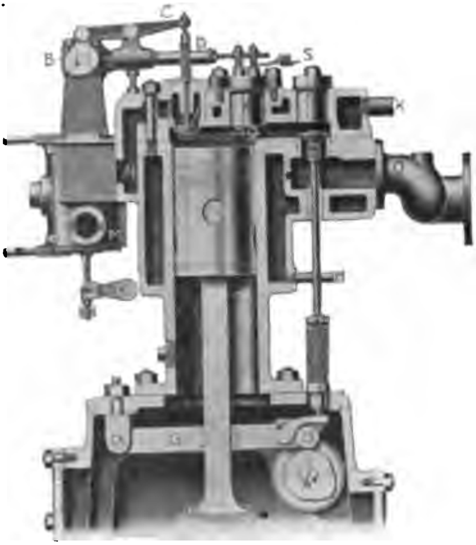


Fig. 6. Ignition.

During the whole of the last return stroke (Fig. 7) the exhaust valve E remains open and the products of combustion are forced through O to the atmosphere. The exhaust valve closes as the piston completes the stroke, and everything is in readiness to recommence the cycle.

Another form of vertical engine using the Otto cycle is shown in vertical section in Fig. 8. In this engine there are three valves—the inlet valve *b* for the gas, the inlet valve *a* for the explosive mixture, and the exhaust valve. All three valves are operated from the shaft *c* which is driven from the main shaft by spur gearing, reducing the speed to one-half that of the main shaft. A cam on the shaft *c* lifts the pivoted lever *d* at the end of which is the long spindle of the valve *a* through which the charge is admitted. The spindle carries an arm *e* which comes in contact with a short link on the

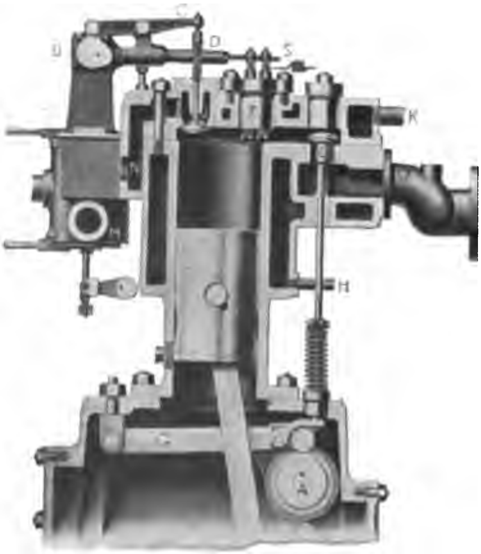


Fig. 7. Exhaust.

stem of the gas admission valve *b* whenever an explosive charge is required, so that both the valves *a* and *b* are open at the same time. The space *g* behind the valve *a* and around the valve *b* is in free communication with the atmosphere. With *a* open and the piston decending, air is drawn in and thoroughly mixed with the gas while passing through *a*. If the governor throws the short link to one side, the arm *e* does not come in contact with it, the gas valve does not open and air alone is taken into the cylinder during the admission stroke. The exhaust valve is behind the admission valve but is not shown in the diagram.

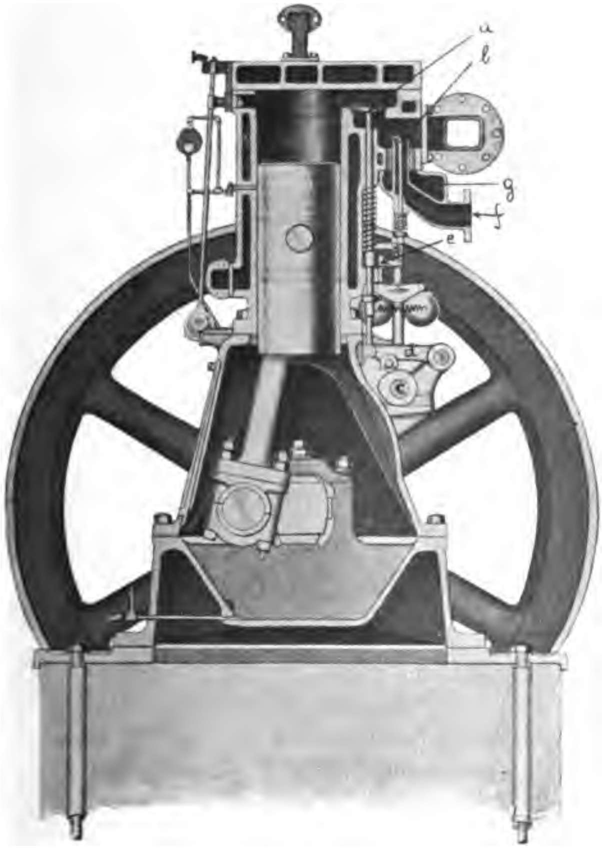


Fig. 8. Nash Gas Engine.

An example of the horizontal form of gas engine is given in Fig. 9, which is a vertical cross section through the cylinder and valves. The valve *a* for the admission of the explosive mixture acts automatically, opening when the pressure in the cylinder falls below the atmospheric pressure. The exhaust valve *b* is opened at the proper time by the action of the cam *c*, which, acting on a roller *d* at the extremity of one arm of the bell crank lever fulcrumed at *e*, pulls the rod *f* to the left and through the bell crank lever fulcrumed at *g* lifts the exhaust valve as shown. The cam *c* is mounted on a shaft which is driven through the spur wheel *k* by the spur wheel *h* (dotted) on the crank shaft. The wheel *k* has twice as many teeth as the wheel *h*, and consequently the cam shaft revolves only half as fast as the main shaft.

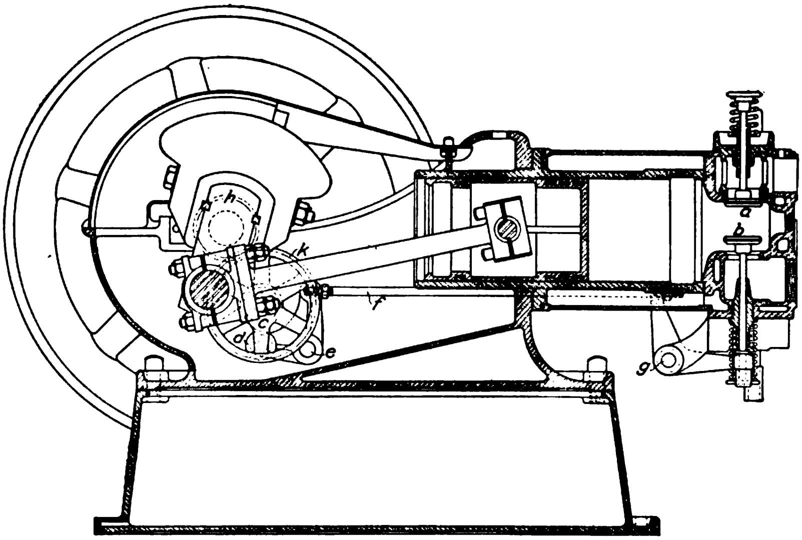


Fig. 9. Olds Engine.

Another horizontal engine is illustrated in Figs. 10, 11 and 12. In this case the admission valve B and the exhaust valve D are both horizontal, a position which can be used satisfactorily only for engines of small size. The air goes to the admission valve through the pipe N, and is shown as taken from the base of the engine. The gas mixes with it at H (Fig. 10), entering through a nozzle. The amount of gas entering is controlled by the throttle valve A (Fig. 11), and the time at which it enters is determined by the valve G, which is opened at the desired time through the action of the cam P (Fig. 11). The cam P coming in contact with the roller Q at the end of the lever fulcrumed at R, gives a movement to the rod S which is transmitted to the valve through the levers best seen in Fig. 12. The admission valve B is automatic in its action. The exhaust valve D is opened by the action of the cam T (Fig. 10) acting on the roller U at the end of the valve rod W. The valve rod is supported near its free end by the lever X. Both the cams P and T are on a shaft driven from the crank shaft by spur wheels. The governor (Fig. 12) is of the fly-wheel type

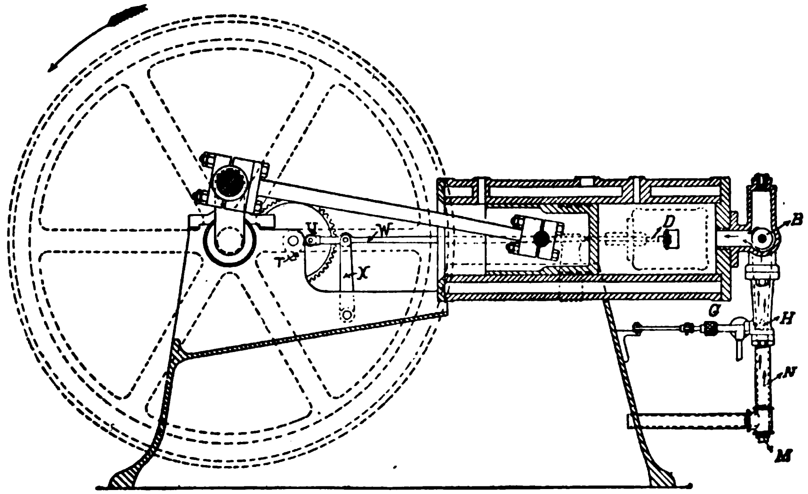


Fig. 10, Charter Engine. Sectional Elevation.

and consists of the balls which are held by spiral springs and which operate a sleeve on the main shaft. When the engine is above speed, the movement of the sleeve throws the roller Q out of line with the cam P, and consequently there is no admission of gas to the cylinder.

The inlet and exhaust valves in gas engines are nearly always *poppet* or *mushroom* valves similar to those shown in Figs. 4 to 11. The exhaust valves are nearly always mechanically operated; the main inlet valves are often automatic. The automatic valve is similar to a pump suction valve and is kept on its seat by a weak spring (*a*, Fig. 9) and only opens when the pressure in the cylinder is sufficiently less than the atmospheric pressure to permit the latter to overcome the resistance of the spring. Consequently the suction or admission pressure in the gas engine is necessarily low when automatic inlet valves are used. The effect is to decrease the work done by the engine and also its efficiency; the only advantage is the greater simplicity. Most small gas engines have automatic inlet valves.

A positively actuated admission valve is shown in Fig. 13. The valve is lifted by a cam *a* on the side shaft *b* through the lever fulcrumed at *c*. The valve closes by its own weight, assisted by a spring, and is guided in its motion by a long sleeve. The valve chest is completely water-jacketed.

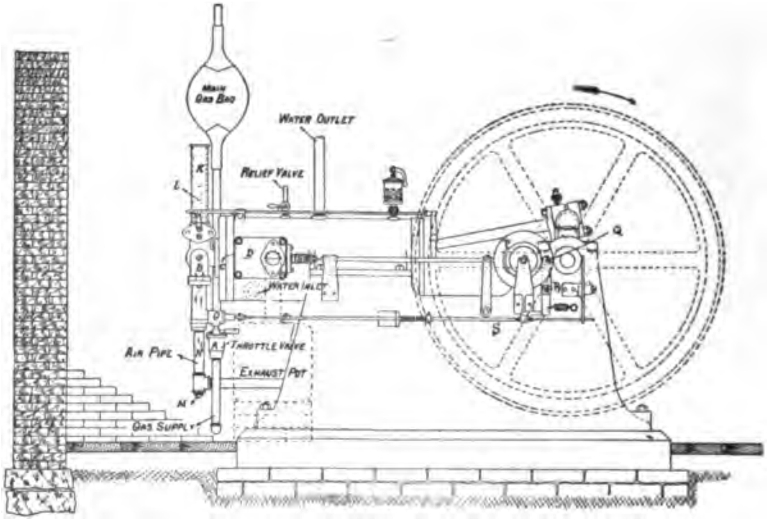


Fig. 11. Charter Engine. Side View.

The pressure in the cylinder when the exhaust valve opens is generally from 25 to 45 lb. above the atmospheric pressure, and the exhaust valve has to be lifted against this pressure. With a mushroom valve 4 in. in diameter, and with 40 lb. pressure per square inch at the end of expansion, there would be a total pressure of about 500 lb. on the valve at the time when it is to be lifted. It is desirable to reduce the strain on the valve and valve mechanism, and in large engines this is sometimes done by balancing the valve. A balanced exhaust valve *e* of the piston valve type is shown in Fig. 14 in its valve chest or housing. The connection with the cylinder is at *d* and the valve seat is the conical seat *a*. A hole *f* through the valve ensures the existence of atmospheric pressure on top of the valve, and the exhaust gases escape through *g* to the atmosphere. To prevent excessive heating of this valve water is circulated through it, entering at *b* and leaving at *c*.

In smaller engines the pressure on the exhaust valve just prior to its opening is sometimes relieved by the escape of the gases through an auxiliary exhaust port (P, Fig. 15) in the cylinder which is uncovered by the piston just before it reaches the end of its outstroke. Soon after it starts on the return stroke the piston covers the auxiliary port, and the exhaust for the remainder of the stroke is through the regular exhaust valve. As the regular valve (not shown in the figure) is not opened till after the uncovering of the auxiliary port, there is practically only atmospheric pressure on it when it lifts. An objection to this device is that the same auxiliary port is uncovered again near the end of the admission stroke, and as the pressure in the cylinder is then less than atmospheric pressure, some of the exhaust gases enter the

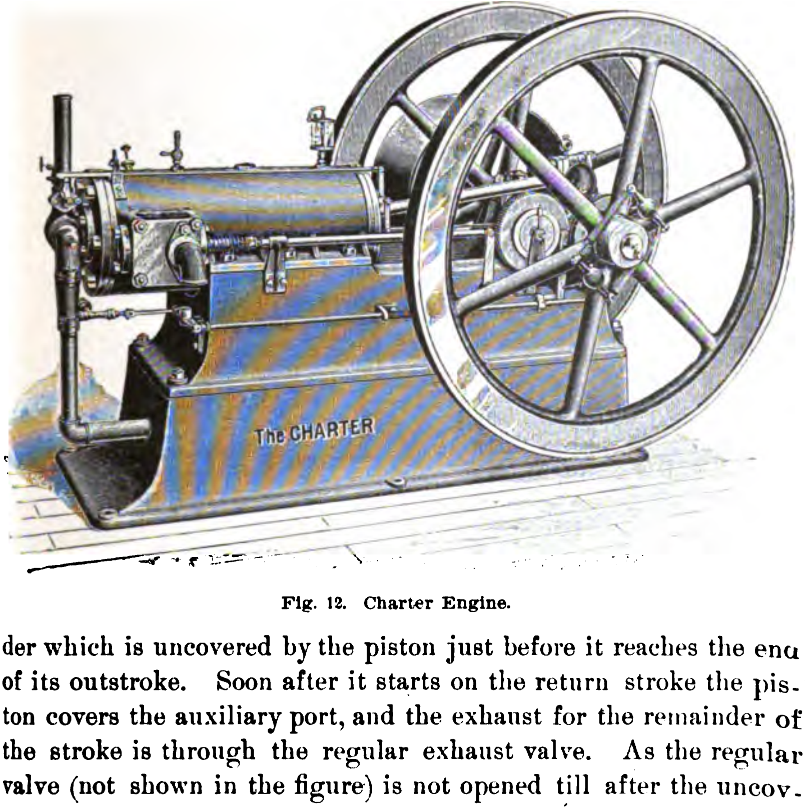


Fig. 12. Charter Engine.

cylinder, mixing with the charge and diluting it. At the beginning of the return or compression stroke part of the contents of the cylinder is forced out to the exhaust until the piston has again covered the auxiliary port, and consequently some of the charge is lost.

Valve Gearing. The valves are most commonly operated by cams. Cams are preferable to eccentrics for this purpose, because they can be designed to give very prompt opening and closing. The cams are mounted upon a *lay shaft*, or *side shaft*, or *cam shaft.* The cam shaft is driven in different engines either by spur gears, bevel gears, or skew gears. The spur gear (see Fig. 12) can be used only for parallel shafts, the bevel gear for shafts which are in the same plane but are inclined to one another, and the skew or spiral gear (Fig. 16) for shafts which are not parallel and do not lie in the same plane. To reduce the speed of the cam shaft the spur and bevel gears must have the gear on the cam shaft twice the size of that on the main shaft. With the skew gear there is no necessary relation between the diameter of the two gears, and generally the gear on the cam shaft is smaller than that on the main shaft. The skew gear has great advantage over the other two in its quietness of operation.

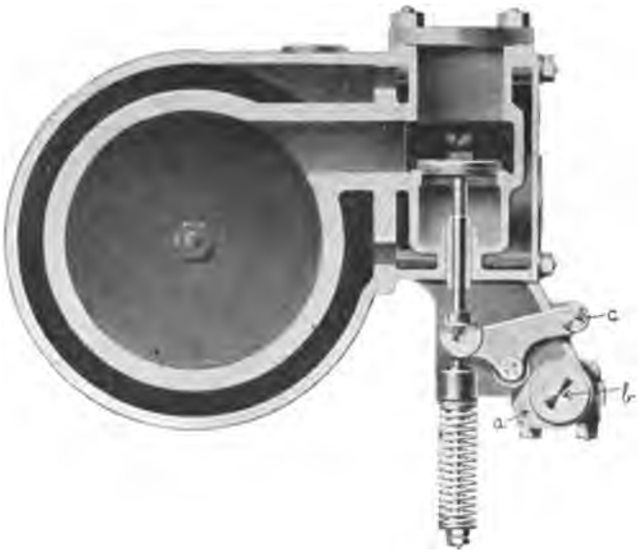
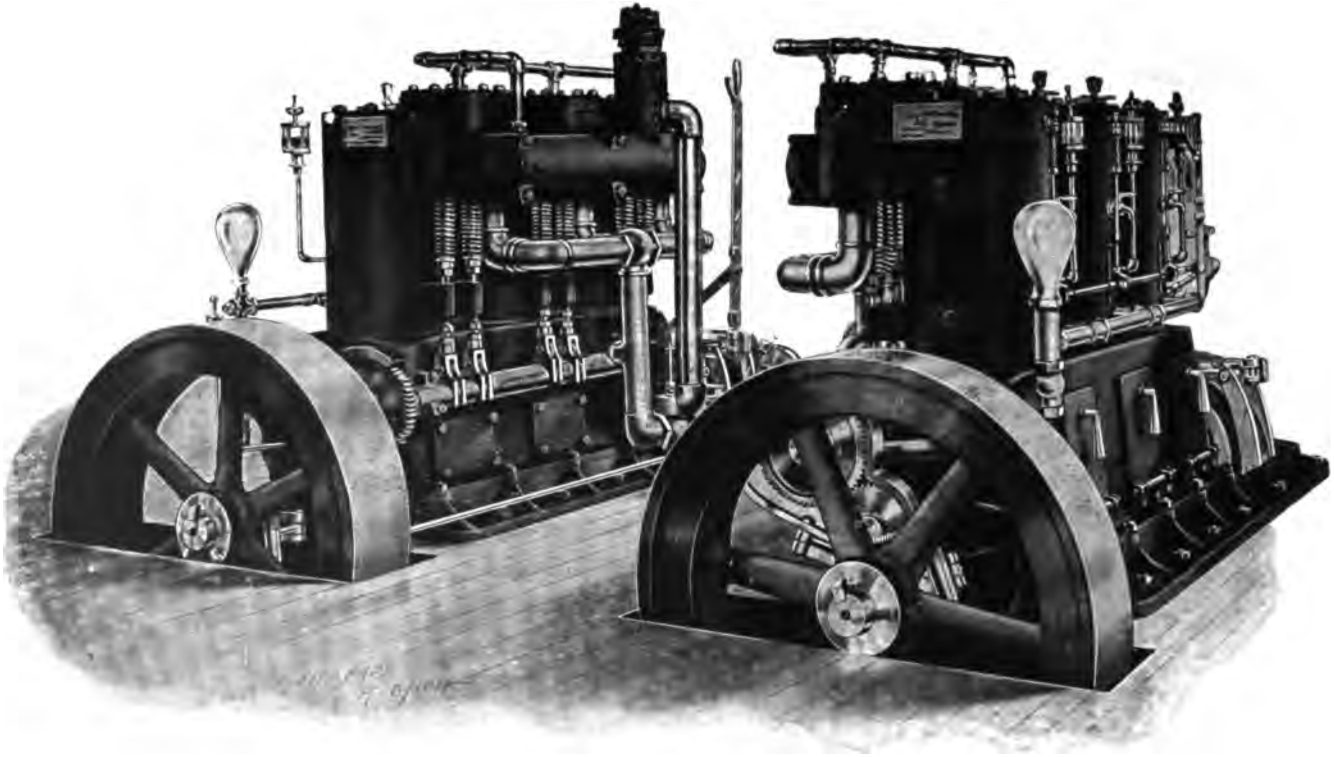


Fig. 13. Buffalo Engine. Cross-Section of Cylinder and Valve Chest.



FORWARD VIEW OF A PAIR OF 27 H.P 3 CYLINDER 4 CYCLE BALANCED TWIN SCREW GAS ENGINES.
Wolverine Motor Works.

THERMODYNAMICS OF THE OTTO CYCLE.

In internal combustion motors the explosive mixture in the cylinder consists of air mixed with a comparatively small volume of the gaseous or liquid fuel. For instance, if the engine uses gas from the city mains, the mixture will average about eight or nine parts of air to one of gas and should never have less than about six parts of air to one of gas. This mixture can be regarded up till the time when explosion takes place as if it were pure air. Also, the products of combustion, after the explosion is completed, have physical properties but very slightly different from those of air, and consequently the working substance in the cylinder can be regarded without serious error as consisting entirely of air. In the following discussion of what occurs in the engine cylinder, it is assumed throughout that the substance in the cylinder is air.

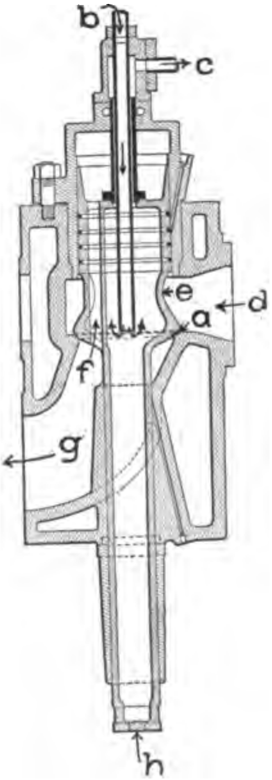


Fig. 14. Balanced Exhaust Valve.

The processes taking place in the engine cylinder are best represented on a pressure-volume diagram. At the beginning of the cycle of operations the piston is at the end of its path and is about to begin its out-stroke. The clearance space is full of products of combustion at atmospheric pressure because it has been in communication with the atmosphere through the exhaust valve which has just closed. The condition existing in the cylinder at this instant is represented in the diagram, Fig. 17, by the point 1, which is at a horizontal distance from the vertical axis representing the clearance volume, and at a vertical distance above the horizontal axis representing the atmospheric pressure of 14.7 lb. per square inch. As the piston makes its out-stroke the admission valve opens admitting the charge to the cylinder throughout the stroke, and as the cylinder is in communication with the outside air through the air admission valve, the pressure in the cylinder remains atmospheric pressure throughout the stroke. On the diagram the admission is represented by the line 1 2, which is at the constant height representing the atmospheric pressure and whose length represents the volume of the charge taken in, which is the same as the volume through which the piston moves. The point 2 represents the condition at the end of the first stroke. The admission valve now closes and the piston makes its return stroke. Since all the valves are closed, the charge cannot escape and is crowded into a smaller volume while its pressure rises. The process continues till the piston reaches the end of its stroke, at which time the whole charge is compressed into the clearance space. This process is represented by the line 2 3, which shows the rise in pressure resulting from the compression. A compression of this kind, occurring without the addition or the abstraction of heat from the gas, is called an *adiabatic* compression. It causes not only an increase in the pressure but also in the temperature of the gas. It is the process that takes place in the working of an ordinary bicycle pump and which causes its rise in temperature. The relation between the pressure of air and its volume when subjected to adiabatic compression is

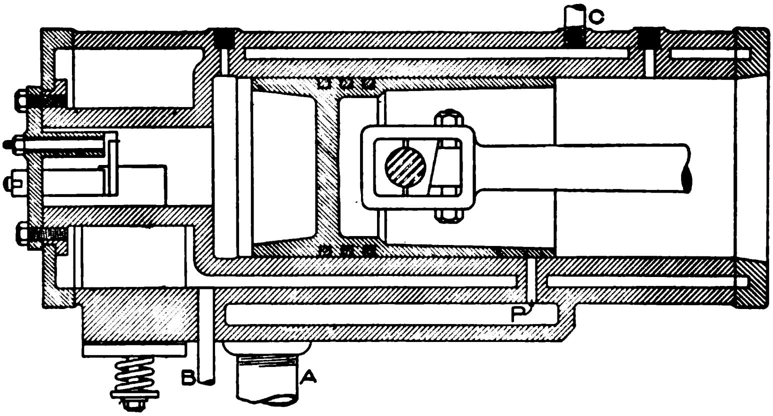


Fig. 15. Section Through Cylinder, Columbus Engine

$$PV^{1.405} = \text{constant}$$

(Note carefully that in this equation P means the absolute pressure and not the pressure shown by a gauge). When the charge has reached the conditions represented by the point 3, it is ignited, and the heat generated by the explosion raises the temperature and consequently the pressure of the mixture. The combustion occurs so rapidly that the piston has not time to start on the out-stroke before the combustion is completed and the rise of pressure occurs, as is shown by the line 3 4, while the volume of the gas is constant. The hot products of combustion at the pressure P_4 now force the piston out and, expanding behind it, they fall in pressure. This expansion, occurring without communication of heat to or from the gas is *adiabatic expansion*, and is consequently accompanied by a fall in temperature of the gas. The expansion curve 4 5 is similar to the compression curve 2 3, and has the same equation.

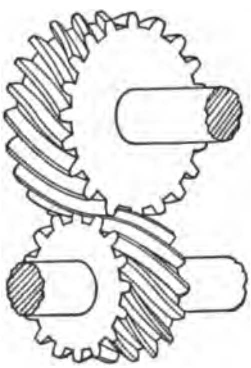


Fig. 16. Spiral Gear.

At the point 5 the piston is at the end of the stroke and no more expansion is possible. The exhaust valve opens and the pressure in the cylinder falls immediately to atmospheric pressure, as shown by the line 5 2 in the diagram. Throughout the last return stroke, 2 1, the exhaust valve remains open so that the pressure in the cylinder remains atmospheric pressure. The completed diagram, Fig. 17, shows the whole series of pressure and volume changes occurring in a gas engine, and is such a diagram as would be taken by an indicator from a perfect engine. The area 2 3 4 5 enclosed by the diagram represents the work done by the engine per cycle.

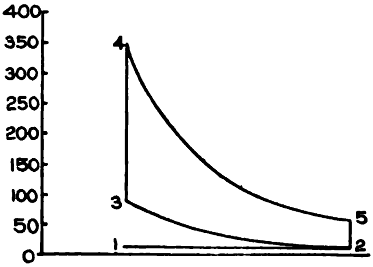


Fig. 17. Ideal Indicator Card of Otto Cycle.

The Pressures and Temperatures of the working substance and the amount of work done in an engine which exactly follows the Otto cycle can be readily calculated. Starting at the point

2 (Fig. 17), there is present in the cylinder a volume V_2 at atmospheric pressure P_2 and at the temperature t_2, which will be assumed to be the temperature of the air as it came into the cylinder. The working substance is compressed adiabatically till it fills only the clearance volume V_3. The consequent rise in pressure can be calculated from the formula already given, but it is more simply obtained from the curve, Fig. 18, which gives the relation between the changes of volume and of pressure in adiabatic expansion or compression.

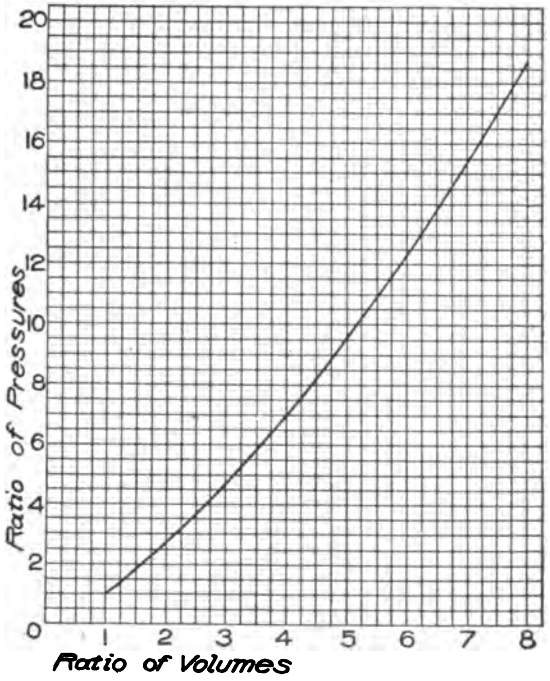


Fig. 18. Adiabatic Expansion.

The horizontal scale in this diagram is the ratio of expansion or compression, and the vertical scale shows the corresponding ratio of the pressures at the beginning and end of the expansion or compression. If, for example, the working substance expands adiabatically to five times its original volume, the pressure (which varies inversely as the volume) is shown by the curve to fall to $\frac{1}{9.67}$ of its original value. Conversely, if the working substance is compressed to $\frac{1}{5}$ the original volume, the pressure rises to 9.67 times its original value. Consequently, the pressure at the point 3, Fig. 17, can be found by the use of this curve.

Example. A gas engine with $33\frac{1}{3}$ per cent clearance takes in its charge at 14.7 lb. per sq. in. pressure. What is the pressure at the end of the adiabatic compression?

Solution The clearance volume V_3 is $33\frac{1}{3}$ per cent of the volume, $V_2 - V_3$, through which the piston moves, or

$$V_3 = \frac{33\frac{1}{3}}{100}(V_2 - V_3)$$

$$\therefore \quad 3V_3 = V_2 - V_3$$

$$\text{and} \quad \frac{V_2}{V_3} = 4$$

From the curve, Fig. 18, if the ratio of compression is 4, the corresponding ratio of pressures is 7.06, so that the pressure at the end of compression is 7.06 times the pressure at the beginning of compression. Therefore the pressure at end of compression, $P_3 = 7.06 \times 14.7 = 103.8$ lb. per sq. in. abs.

The temperature at the end of the adiabatic expansion can be found from the equation for a perfect gas. This may be stated in the form

$$PV = wRT$$

where w is the weight of the gas, R is a constant for any perfect gas and has the value 53.2 for air, P is the pressure in lb. per sq. ft. abs., and T is the absolute temperature of the gas. The weight of the gas is constant throughout the adiabatic compression, and can be found from the point 2 if P_2, V_2 and T_2 are known. The temperature at 3 can then be found from the equation

$$P_3V_3 = wRT_3$$

Example. Assuming the conditions of the previous problem and supposing the temperature of the air to be 60° F., what is the temperature of the charge at the end of the compression?

Solution.

$$P_2V_2 = wRT_2$$

$$\therefore \quad wR = \frac{P_2V_2}{T_2} = \frac{14.7 \times 144 \times V_2}{60 + 461}$$

Also

$$T_3 = \frac{P_3V_3}{wR}$$

$$= P_3 \frac{V_3}{V_2} \times \frac{60 + 461}{14.7 \times 144}$$

and

$$\frac{V_3}{V_2} = \frac{1}{4}$$

$$\therefore \quad T_3 = 103.8 \times 144 \times \frac{1}{4} \times \frac{521}{14.7 \times 144}$$

$$= 919.6^\circ \text{ abs.}$$

and

$$t_3 = 458.6^\circ \text{ F.}$$

The rise in temperature during explosion depends on how much heat is generated which in turn depends on the strength of the explosive mixture and the heat of combustion of a cubic foot of the fuel. Let H be the heat of combustion of a cubic foot of the fuel in B. T. U., and let the mixture consist of 1 part of gas to n parts of air. The total volume of the charge taken into the cylinder each admission is

$$V_2 - V_1 \text{ cu. ft.}$$

the volume of fuel in this charge

$$\frac{1}{n+1}(V_2 - V_1)$$

and the heat of combustion of this fuel is

$$Q = H \frac{V_2 - V_1}{n + 1} \text{ B.T.U.}$$

This heat is utilized in raising the temperature of the gas from the known temperature T_3 to another temperature T_4. The rise in temperature can be found when the heat necessary to raise one pound of air one degree in temperature is known. This amount of heat is called the *specific heat.* It is represented by the symbol C_v (indicating that the volume is unchanged while the temperature rises), and is equal to .169 B.T.U. for air. With a weight of w

lb. the heat necessary to raise the gas one degree in temperature is

$$wC_v \text{ B.T.U.}$$

To raise the temperature $T_4 - T_3$ degrees the heat supply is

$$w\ C_v\ (T_4 - T_3) \text{ B.T.U.}$$

and the heat of combustion is used entirely in raising the gas from T_3 to T_4.

$$\therefore\ H\frac{V_2 - V_1}{n + 1} = w\ C_v\ (T_4 - T_3)$$

$$= \frac{P_2V_2}{RT_2}C_v\ (T_4 - T_3)$$

$$T_4 - T_3 = \frac{H}{n + 1} \times \frac{RT_2}{P_2} \times \frac{1}{C_v} \times \frac{V_2 - V_1}{V_2}$$

Example. In the previous problem if the charge taken in consists of 1 part of gas to seven parts of air and the heat of combustion of the gas is 640 B.T.U., per cu. ft., find the temperature at the end of explosion.

Solution.

$$\frac{V_2 - V_1}{V_2} = \frac{V_2 - \frac{1}{4}V_2}{V_2} = \frac{3}{4}$$

$$T_4 - T_3 = \frac{640}{8} \times \frac{53.2 \times 521}{14.7 \times 144} \times \frac{1}{.169} \times \frac{3}{4}$$

$$\therefore\ T_4 = 4649 + T_3$$

$$= 5568.6^\circ \text{ abs.}$$

$$\therefore\ t_4 = 5107.6^\circ \text{ F.}$$

If a perfect gas is raised in temperature while its volume is unchanged, the absolute pressure will increase in exact proportion to the rise of absolute temperature,

or $$P_4 : P_3 :: T_4 : T_3$$

$$\therefore\ P_4 = \frac{T_4}{T_3}P_3$$

Example. What is the pressure at the end of explosion in the preceding problem ?

Solution.

$$
\begin{aligned}
P_4 &= \frac{T_4}{T_3} P_3 \\
&= \frac{5568.6}{919.6} \times 103.8 \text{ lb. per sq. in. abs.} \\
&= 628.6 \text{ lb. per sq. in. abs.}
\end{aligned}
$$

The pressure and temperature at the end of the adiabatic expansion can be found most simply, after the other pressures and temperatures are known, by making use of a relation which exists between the pressures and temperatures at the points 2, 3 4. 5.* These relations are

$$\frac{P_2}{P_3} = \frac{P_5}{P_4}$$

and

$$\frac{T_2}{T_3} = \frac{T_5}{T_4}$$

Examples. What are (a) the pressures and (b) the temperatures at the end of the adiabatic expansion in the preceding problem?

(a) $P_5 = \frac{P_2}{P_3} \times P_4 = 89$ lb. per sq. in. abs.

(b) $T_5 = \frac{T_2}{T_3} \times T_4 = 3155^\circ$ abs.

$= 2694^\circ$ F.

The work done by any heat engine is equal to the difference between the heat that goes to the engine and that which is rejected by the engine, because whatever heat disappears cannot have been destroyed and must have been converted into work. In the Otto cycle the heat taken in has been seen to be

$$Q = wC_v (T_4 - T_3) \text{ B.T.U.}$$

Heat is rejected from the engine only during the process represented by the line 5 2, because when the charge gets back to the condition 2, it has returned to its original volume and pressure and consequently to its original temperature. The heat rejected is then

---

* The ratio of the pressures $\frac{P_4}{P_5}$ can be obtained from the curve, Fig. 18, since the ratio of the volumes $\frac{V_5}{V_4}$ is known. But $V_4 = V_3$, therefore $\frac{V_5}{V_4} = \frac{V_2}{V_3}$ and $\frac{P_3}{P_2} = \frac{P_4}{P_5}$

$$Q_R = wC_v\,(T_5 - T_2)\ \text{B.T.U.}$$

And consequently the work done per cycle is

$$\begin{aligned} W &= Q - Q_R\ \text{B.T.U.} \\ &= 779\,(Q - Q_R)\ \text{ft. lb.} \end{aligned}$$

The efficiency of the cycle, that is, the fraction of the heat supplied that is converted into work is

$$\begin{aligned} E &= \frac{W}{Q} = \frac{Q - Q_R}{Q} \\ &= 1 - \frac{Q_R}{Q} \\ &= 1 - \frac{T_5 - T_2}{T_4 - T_3} \end{aligned}$$

And since, as already stated,

$$\frac{T_5}{T_4} = \frac{T_2}{T_3}$$

we get
$$\frac{T_5 - T_2}{T_4 - T_3} = \frac{T_2}{T_3}$$

therefore
$$E = 1 - \frac{T_2}{T_3}$$

Example Find the efficiency of the cycle in the preceding problem.

$$\begin{aligned} E &= 1 - \frac{T_2}{T_3} \\ &= 1 - \frac{521}{919.6} \\ &= 1 - .567 = .433 \end{aligned}$$

The work W done per cycle can be calculated from the efficiency, without knowing the heat rejected

$$E = \frac{W}{Q}$$

or
$$\begin{aligned} W &= E \times Q\ \ \text{B.T.U.} \\ &= 779\,E \times Q\ \ \text{ft. lb.} \end{aligned}$$

Examples. If the cycle discussed in the previous examples takes place in a cylinder of 12 in. diameter and 18 in. stroke, what will be the work done per cycle? If the engine makes 250 revolutions per minute, what will be its indicated horse-power?

Solution.

$$W = 779\ E \times Q \quad \text{ft. lb.}$$

$$Q = \frac{H}{n+1}\,(V_2 - V_1) \quad \text{B.T.U.}$$

$V_2 - V_1$ is the volume through which the piston moves in cu. ft., and is the product of the cross section area of the cylinder in sq. ft. by the stroke in ft.

$$\therefore \quad V_2 - V_1 = \frac{\pi}{4} \times \left(\frac{12}{12}\right)^2 \times \frac{18}{12}$$

$$= 1.178 \text{ cu. ft.}$$

$$\therefore \quad Q = 94.25 \text{ B.T.U.}$$

$$\therefore \quad W = 40.81 \text{ B.T.U.}$$

$$= 31791 \text{ ft. lb.}$$

Since this engine requires two revolutions to complete a cycle, the number of cycles per minute is only half the number of revolutions per minute; therefore the work per minute

$$= W \times 125 \quad \text{ft. lb.,}$$

and the horse-power

$$= \frac{31791 \times 125}{33000},$$

$$= 120.4 \text{ I.H.P.}$$

EXAMPLE FOR PRACTICE.

(a) A gas engine using the Otto cycle has 25 per cent clearance and takes in its charge at 14.7 lb. per sq. in. and at 60° F. What is the pressure at the end of the compression?

Ans. 141.1 lb. per sq. in. abs.

(b) What is the temperature at the end of compression?

Ans. 539° F.

(c) If the charge consists of 1 part of gas to 9 parts of air and the heat of combustion of the gas is 600 B.T.U. per cu. ft. what is the temperature at the end of explosion? Ans. 4258° F.

(d) What is the pressure at the end of explosion?

Ans. 665.9 lb. per sq. in. abs.

(e) What are the pressure and temperature at the end of the expansion? Ans. 69.4 lb. per sq. in. abs. 1997° F.

(f) What is the efficiency of the cycle? Ans. .479.

(g) If the cylinder diameter is 18 in. and the stroke is 24 in., and the engine makes 150 revolutions per minute, what is the I.H.P.? Ans. 180 I.H.P.

An examination of the equation for the efficiency of the Otto cycle.

$$E = 1 - \frac{T_2}{T_3}$$

brings out certain important results. The efficiency is seen to depend only on the ratio of the temperatures at the beginning and end of the compression, and not at all upon the temperature and pressure at the end of explosion. Since the ratio of the temperatures at the beginning and end of compression depends only upon the ratio of compression, and since further, the charge is always compressed till it occupies the clearance volume, the efficiency is seen to depend only upon the percentage clearance. In other words, in engines with the same percentage clearance using the Otto cycle, the percentage of the heat liberated in the cylinder that is converted into work is always the same whatever be the size of the engine or the strength of the charge. The effect of the clearance on the efficiency is exhibited in table I, where it is seen that the smaller the clearance the greater is the efficiency of the engine. The pressures at the end of compression are also given in the table, and are calculated on the assumption that the atmospheric pressure is 14.7 lb. per sq. in. abs.

TABLE I.

Percentage Clearance of Otto cycle engine.	Pressure at the end of compression lb. per sq. in. abs.	Efficiency of Otto cycle.	Efficiency of cycle with increased expansion, but with the same compression pressure as the Otto cycle.
20	183.3	51.6	60.9
25	141.1	47.9	58.4
30	115.4	44.8	55.
35	98.	42.1	52.5
40	85.5	39.8	50.4

OTTO CYCLE WITH INCREASED EXPANSION.

The pressure at the end of expansion is seen in the example worked out to be 89 lb. per sq. in. abs. In ordinary practice it is commonly found to be from 50 to 60 lb. abs. It is evident that if the gas were permitted to expand further it would do more work and consequently would increase the efficiency of the cycle. The indicator card, Fig. 19, shows one method used for obtaining more expansion. The charge enters at atmospheric pressure from 1 to 2, when the admission is cut off. The piston continues moving forward to the end of its stroke, but as no more admission takes place the charge expands adiabatically to 3, while its pressure falls. On the return stroke the charge is compressed adiabatically, retracing the expansion path along 3 2 and continuing till the whole charge is compressed into the clearance space at 4. The rest of the cycle is unchanged. The diagram 1 2 4 5 8 2 represents the ordinary Otto cycle, and the shaded area 8 6 7 2 represents the increase in work due to the increased expansion. The efficiency of this cycle can be easily calculated and the results of such calculations are given in table I. They are made on the assumption that the charge is admitted for only one-half the stroke and that the heat combustion is 80 B.T.U. per cu. ft. of the charge. An inspection of the table shows the increase in efficiency which results from the increased expansion for engines which have the same pressures at the end of compression and indicates that in order that a gas engine of this type should be of high efficiency, it should compress the charge to a high pressure, and then should expand the products of combustion to a volume considerably in excess of the original volume of the charge.

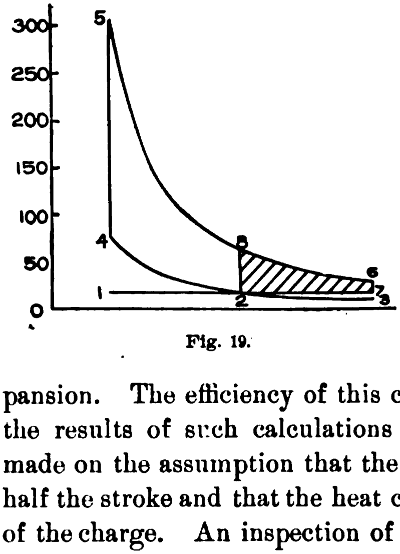


Fig. 19.

THE IDEAL AND THE REAL OTTO CYCLES.

The calculations in the preceding pages are made on the assumption that the gas engine follows the Otto cycle exactly, in which case the engine is called an *ideal* engine. The *real* engine does not exactly follow the Otto cycle because of certain practical difficulties. Differences between the real and the ideal engines occur in each part of the cycle. During admission (Fig. 20, line 1 2) the pressure in the cylinder is actually a pound or more below the atmospheric pressure, that difference being necessary to open the air admission valve (when automatic), and to cause the air to flow in with sufficient velocity. The charge, moreover, is heated by contact with the cylinder walls and with the hot gases remaining in the clearance. The compression is not adiabatic because it occurs in a cast iron cylinder which takes heat from the gas while it is being compressed and so makes the final temperature and pressure less than that calculated on the assumption of adiabatic expansion. The difference, generally, is not very great.

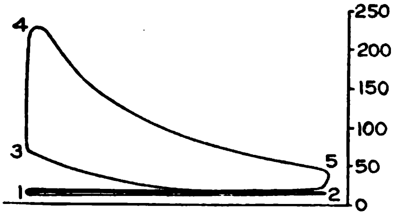


Fig. 20. Indicator Card from Otto Cycle Engine.

The explosion in the real engine is neither instantaneous nor complete. It approximates more closely to the ideal explosion when the compression is considerable and when the explosive mixture has only a small excess of air present. With weaker mixtures the explosion becomes slower and less complete, as shown in Fig. 21, till, with the weakest explosive mixture, the process is really one of slow combustion taking place throughout the whole of the expansion period, and some of the charge may be still unburned when exhaust takes place. Even under the best conditions the rise of temperature, and consequently of pressure, during the explosion is only about six-tenths of that occurring in the ideal engine. This, it will be seen, makes the power of the real engine considerably less than that of the ideal. The water jacket around the cylinder, without which the cylinder would be too hot to be properly lubricated, is one of the

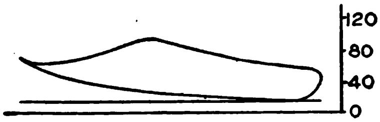


Fig. 21. Indicator Card with Weak Mixture.

important causes of the difference between the real and ideal cycles, as the jacket absorbs usually about forty per cent of the total heat of the combustion.

The expansion curve is above the adiabatic in real engines because the cylinder walls that have been heated by the explosion give back some heat to the gases and also because the combustion still continues and liberates more heat. This last effect is especially marked when the explosive mixture is weak.

Finally, the exhaust, as in the steam engine, begins a little before the end of the expansion stroke so as to give plenty of time for the escape of the gases, and the pressure in the cylinder during the exhaust stroke is necessarily higher than that of the atmosphere into which the gases are rejected.

The total effect of all these differences between the real and the ideal engine is that the work done in an actual engine in good condition is only from five-tenths to six-tenths of that which the ideal engine would do, and the efficiency of the real engine is only from five-tenths to six-tenths of that of the ideal engine.

Example. What are the probable actual efficiency, horse-power and gas consumption of the engine whose ideal performance has been worked out in the preceding examples? Assume the real engine to have $\frac{6}{10}$ the efficiency of the ideal engine.

The ideal efficiency was found to be .433.

$\therefore$ The probable real efficiency $= .6 \times .433 = .26$.

The ideal horse-power was found to be 120.4,

the probable real H. P. $= .6 \times 120.4 = 72.2$.

The gas consumption is expressed in cu. ft. per I.H.P. per hour. In the ideal engine the volume of gas taken in per cycle was

$$\frac{V_2 - V_1}{n + 1} = \frac{1.178}{8} = .147 \text{ cu. ft.}$$

The number of cycles per minute was 125.

$$\therefore \text{ the gas used per minute} = .147 \times 125 \text{ cu. ft.} = 18.4 \text{ cu. ft.}$$

$$\therefore \text{ the gas used per hour} = 18.4 \times 60 \text{ cu. ft.} = 1104. \text{ cu. ft.}$$

And the probable real I.H.P. is 72.2.

$$\therefore \text{ the gas used per I.H.P. per hour} = \frac{1104.}{72.2} = 15.3 \text{ cu. ft.}$$

EXAMPLE FOR PRACTICE.

What are the probable actual efficiency, I.H.P. and gas consumption of the engine whose ideal performance has been worked out in the previous examples for practice.

Answers: .287 efficiency.
108 I.H.P.
14.71 cu. ft. gas consumption.

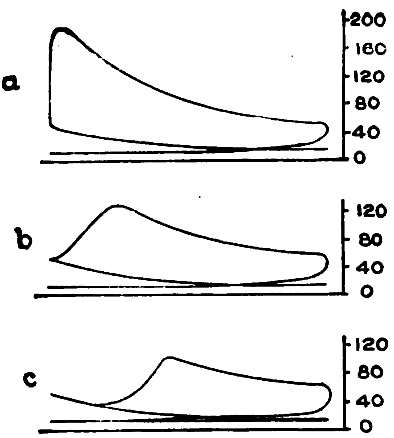


Fig. 22.

Ignition. For satisfactory action of a gas engine the ignition of the explosive mixture must be certain and must occur at a definite predetermined time. In *timing* the ignition it has to be recognized that the explosion is not instantaneous but requires the lapse of a not inconsiderable period of time before the maximum pressure is reached. The actual duration of the explosion depends on the strength of the explosive mixture and on the amount of compression to which it is subjected. The ignition should have *lead*, that is, should begin a little before the end of the return or compression stroke, when the crank is about 15° from its dead center, so that the maximum pressure is reached when the crank has just passed the dead center. The indicator card, *a*, Fig. 22, is with properly timed ignition. If the ignition is later than this, indicator cards similar to *b* or *c* will be obtained, and the engine will do less work and be less efficient. If the ignition is too early, the maximum pressure will be obtained (Fig. 23) before the crank has reached its dead center and will tend to reverse the engine. This causes great shock to the engine, its rapid deterioration and low-

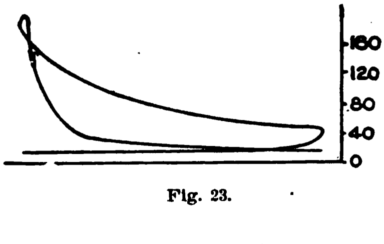


Fig. 23.

ered efficiency. The immediate external evidence of too early or premature ignition, from whatsoever cause, is a violent pounding noise in the engine.

Two methods of ignition are in common use in engines using the Otto cycle. The first is by bringing the explosive mixture into contact with some surface which is kept at a temperature sufficiently high to cause ignition; the second is by means of an electric arc. A hot tube is the common device when the first method of ignition is used. The tube E (Fig. 24) is closed at the upper end and communicates at its lower end through the port B with the cylinder A. It is heated by an external flame from the Bunsen burner C, and is maintained at a full red heat. The chimney around the tube is lined with asbestos and keeps the flame in good contact with the tube. During the admission stroke the tube is filled with products of combustion at atmospheric pressure remaining from the previous explosion. As compression goes on, the non-explosive products of combustion are crowded into the upper part of the tube while part of the explosive mixture in the cylinder is compressed into the lower part of the tube. The length of the tube and the position of the flame are adjusted by experiment so that the explosive charge will just reach the hot portion of the tube and be ignited at the moment when ignition is desired. Shortening the tube makes the ignition come earlier. With this device the actual time of ignition is not very definite. It depends on the temperature of the tube, the position of the Bunsen flame, the strength of the

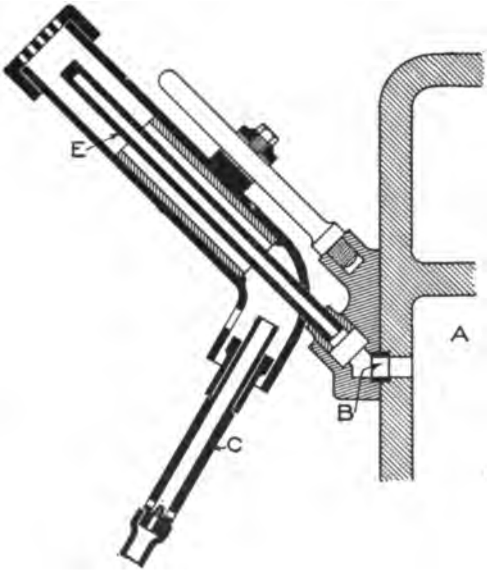
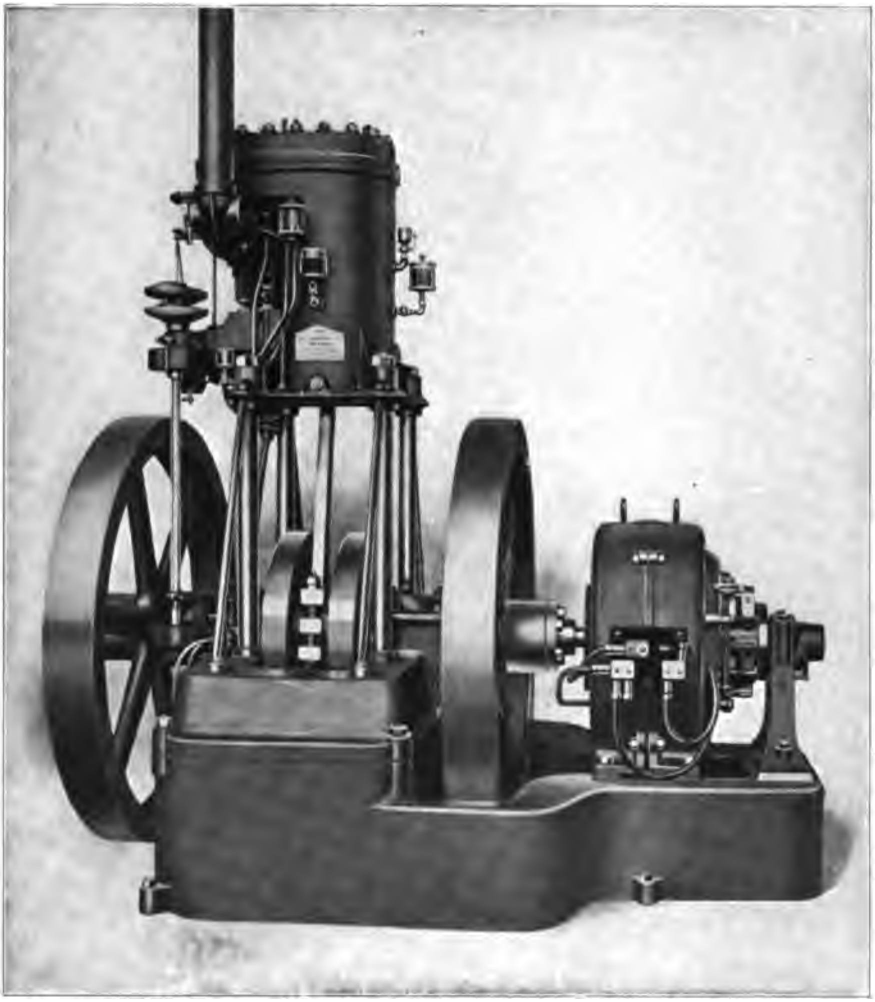


Fig. 24. Hot Tube Igniter.



15 KILOWATT, 250 LIGHT.
Secor Oil-Electric Generating Plant.

mixture and the amount of compression. As these last two quantities are purposely varied by the governor in some engines, irregular timing would result from its use in such cases.

The irregularity of timing with the hot tube igniter can be partly remedied by the use of a *timing valve*. The timing valve B (Fig. 25) is held on its seat by a spiral spring D until ignition is desired, when by a movement of the bell crank lever E the valve opens and the compressed charge in the cylinder A gets access to the hot tube C. The valve B is kept open till the end of the exhaust stroke. The tubes are preferably made of nickel alloy or of porcelain, but the latter is very brittle and apt to break when being fastened in place. Iron tubes are used sometimes, but they burn out rapidly and are unreliable.

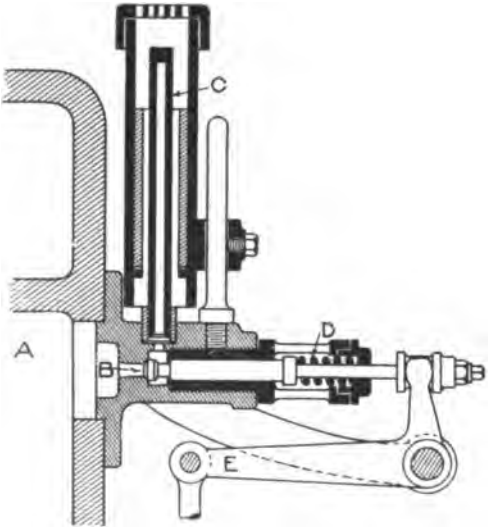


Fig. 25. Hot Tube Igniter with Timing Valve.

Even when provided with a timing valve the hot tube does not give very satisfactory ignition; and, moreover, some time is consumed in heating the tube before the engine can be started. Accurate timing can be obtained best by electric means, and *electric ignition* is consequently used more than any other. The method is to make a spark pass at the instant when ignition is desired between two terminals situated in the clearance space of the engine. The most common way of forming the spark is to separate two contact points through which a current has been flowing. An electric arc will then pass between the separating contact points. In order to ensure that the temperature of the arc is high enough and its duration is sufficient to ignite the explosive mixture through which it passes, a *spark coil* is generally inserted in the circuit. A spark coil consists merely of a bundle of soft iron wires surrounded by a coil of insulated copper wire, through which the current goes. The contact points of the igniter must be brought together to re-establish the current before another spark can be obtained. A device of this nature is known as a *make-and-break* igniter; and when the contact points do not slide across one another, it is called a *hammer break* contact.

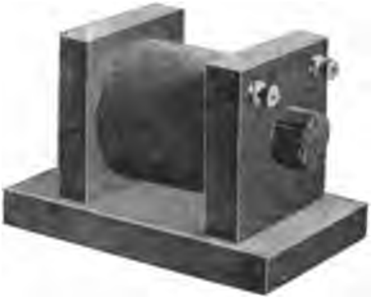


Fig. 26. Spark Coil.

One of the common forms of hammer break igniter is illustrated in Fig. 27, which shows an igniter plug removed from the cylinder head. The movable electrode *b* is at the end of an arm which is fastened to the spindle *c*. When the interrupter lever *d*, which is loose on the spindle *c*, and is connected to it through a coiled spring, is lifted by an arm from the cam shaft of the engine, it rotates the spindle *c* so as to bring *b* into hard contact with the stationary and thoroughly insulated electrode *a*. This completes a circuit and permits a current to flow from *a* to *b*. When ignition is desired the lever *d* is tripped and flies back, carrying with it the shaft *c*, abruptly breaking the contact and causing an electric arc to form between *a* and *b*. The contact points are generally made of platinum, as this does not oxidize or corrode, but other metals are also used. The passage of the spark takes minute particles of the material from one terminal and deposits them on the other, the action following the direction of the current. By reversing the direction of the current, the material may

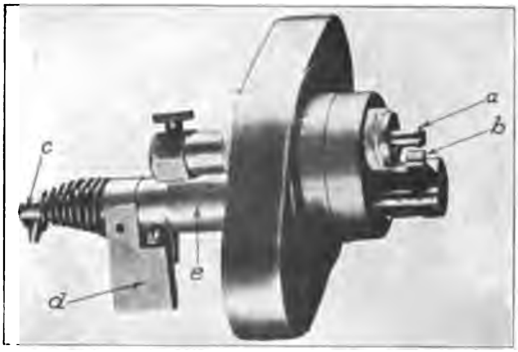


Fig. 27. Otto Engine Igniter Plug.

be returned to the terminal from which it was taken, and the durability of the contact points considerably increased.

The current is generally taken from a primary battery, consisting of about five cells. The Edison-Lalande cell, made up of two zinc plates and a plate of compressed copper oxide immersed in a strong solution of caustic soda, is perhaps the most largely used. Other sources of electricity can be used. Current is sometimes taken from a direct current lighting or power circuit, but this is objectionable because the circuit is grounded every time the igniter terminals are in contact. The practice is growing of using a small special dynamo for the exclusive purpose of supplying the current for ignition. This makes the ignition spark more certain and of more uniform strength than when a battery is used, as the latter deteriorates and weakens with use.

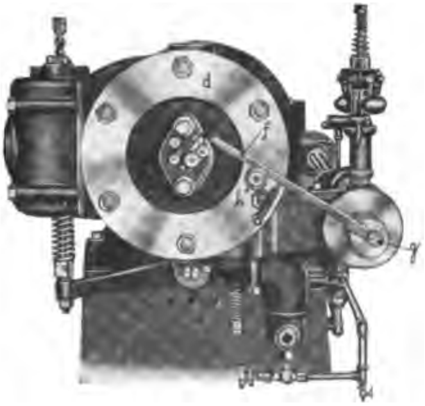


Fig. 28. Igniter Gear of Root and Van Dervoort Engine.

A make-and-break contact is sometimes obtained by sliding one contact point over the other until it slides off completely. This is known as a *wipe break*. The method ensures a good contact, produces a very hot spark, keeps the contact points clean, but wears them out quite rapidly. Provision must be made for adjustment, otherwise the timing will alter with the wear of the points. The rubbing surfaces can be of iron.

The igniter gear of an engine with hammer break ignition is shown in Fig. 28. The igniter rod *f*, which is supported on the reel *h*, receives a reciprocating motion from a crank *g* at the end of the side shaft. During the exhaust or admission stroke the end of the rod *f* comes in contact with the interrupter lever *d* (compare with Fig. 27) and establishes the contact of the electrodes. The vertical component of the movement of the end of the rod *f* sets free the lever *d* at the moment when ignition is desired.

A switch (Fig. 29) should always be included in the electric circuit and should be thrown out when the engine is not running, so as to prevent the short-circuiting and consequent exhaustion of the batteries.

Another way of obtaining electric ignition is known as the *jump spark* method. In this system the terminals are stationary, generally from one-sixteenth to one-eighth of an inch apart, and the spark is made to spring across the gap between them by putting the terminals in the secondary circuit of a Ruhmkorff or *induction coil*. This coil consists of a core of soft iron wire around which is wound a relatively coarse insulated wire, the *primary circuit*, through which the current from the source of energy flows. A relatively fine insulated wire coil, the *secondary circuit*, is wound around the primary coil, but has no metallic contact with it. If the current flowing through the primary circuit is varied in strength, it creates or induces a current in the secondary circuit. Generally the Ruhmkorff coil is provided with a magnetic vibrator (similar to that used in an electric bell), which makes and breaks the primary circuit with great rapidity and induces a considerable alternating current in the secondary circuit. If the two ends of the secondary coil be brought close to one another, but not quite in contact, a spark will jump across the gap at each make and break of the primary current, the spark at the break being the more powerful. For ignition of the explosive mixture in a gas engine it is not necessary to use a vibrator; the cam shaft of the engine breaks the primary circuit at the instant when explosion is desired. The spark passing on the subsequent

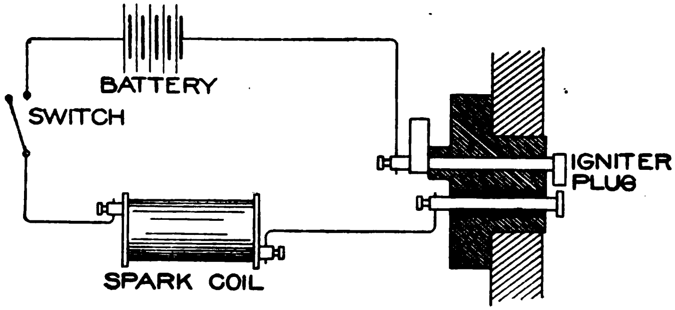


Fig. 29. Diagram of Igniter Circuit.

remaking of the primary circuit is not strong enough to ignite the charge. The connections for jump spark ignition are shown diagrammatically in Fig. 30. The primary circuit is shown there as being completed through a cam on the side shaft of the engine. As soon as the side shaft has moved from the position shown, the contact with the upper flat spring is broken and the primary current is interrupted, thereby inducing sufficient current in the secondary circuit to make a spark pass across the air gap between the terminals of the spark plug. These terminals are completely insulated, so that the only path for a current between them is across the air gap.

The jump spark method has as its great advantage the absence of moving parts inside the cylinder. This is offset by the fact that the spark is liable to fail as a result of the formation of deposits of rust or corrosion on the points, the liability to this being much greater than in either of the make-and-break methods. The difficulty of obtaining satisfactory insulation is also greater.

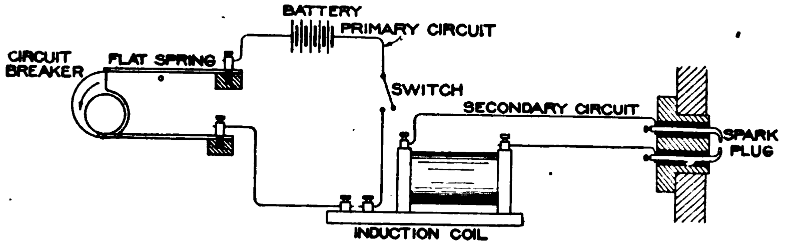


Fig. 30. Diagram of Jump Spark Igniter and Connections.

Governing. The governing of an engine means the control of the power which it is developing so that its speed is maintained practically constant. If the engine develops more power than is required, the engine will speed up; if the power delivered to the crank shaft is less than the resistance there, the engine will slow down. The governing of a gas engine, like that of the steam engine, is effected by utilizing small variations of engine-speed resulting from change of engine load. The controlling mechanism, or the governor proper, does not differ from that used on the steam engine, but there is a considerable difference in the way in which it controls the work done by the engine. There are two general methods in use in gas engines for varying the power; one by varying the number of explosions or impulses per minute, which is known as the *hit-and-miss* system, and the other by varying the magnitude of the impulse while keeping the number per minute constant, which may be called the *variable impulse* system.

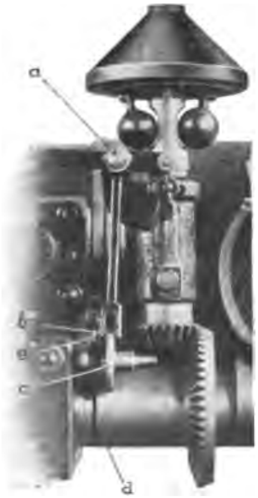


Fig. 31. Governor of Otto Engine.

The Hit-and-Miss System. The omission of the explosion or impulse can be obtained in several ways. The most common method is to keep the gas admission valve closed so that air alone is taken in during the admission stroke, and consequently there is no explosion. A method of accomplishing this is to be seen in Fig. 31, in which a loaded centrifugal governor is shown driven by bevel gearing from the cam shaft. In the position shown, the gas admission cam *d* will come under the reel *c*, and will start to lift it at the beginning of the admission stroke. The reel *c* is loose on a spindle at the end of the horizontal lever *e*, and the vertical rise of the spindle due to the action of the cam opens the gas valve by a system of levers not shown in the figure. If the engine speeds up, the rise of the governor balls raises the sleeve on the governor spindle, lifts the horizontal arm of the bell crank lever fulcrumed at *a* and shifts the forked end *b* of the vertical arm to the right, carrying the reel *c* with it, so that the cam no longer engages it and no gas is admitted. When the speed comes down to the normal speed, the reel is moved back and the admission of gas again takes place. This method is open to the objection common to all the hit-and-miss methods that it makes the speed of the engine very irregular at any other than full load. Even at full load, with the Otto cycle occurring in a single acting cylinder, there is only one motive stroke or impulse in four strokes instead of one every stroke as in a double acting steam engine. If the engine governs by the hit-and-miss method and is running at half load, half the explosions will be omitted and there will be but one motive stroke in eight; at one-third load, there is but one motive stroke in twelve; and at quarter load, one in sixteen. Running at quarter load, the engine will be speeded up during the motive stroke and will slow down during the succeeding fifteen strokes till it gets to normal speed again. The actual variation in speed at low loads can be reduced by the use of heavy fly wheels, but with this method of governing it is too great for use when close regulation is necessary, as for electric lighting. There is an incidental advantage in the use of this method in that, during the idle cycles, the cylinder is flushed out by the *scavenging* charge of air, which makes the next explosion more powerful.

The omission of an explosion is sometimes effected in engines which have an automatic admission valve by the action of the governor in keeping the exhaust valve open throughout the cycle. The free communication between the cylinder and the outside through the exhaust valve prevents the pressure in the cylinder from falling sufficiently below the atmospheric pressure, during the admission stroke, to cause the inlet valve to open. The cylinder contains only products of combustion, substantially at atmospheric pressure, so long as the exhaust is open, and consequently no explosion can occur.

The Variable Impulse System. The amount of work done in a given gas engine depends on the strength of the charge, on its amount, on the timing of the ignition, and on several other factors. The engine can be governed by the variation of *any one* of these, and the three specifically mentioned are all in regular use for this purpose.

If the governing is effected by *varying the strength of the charge*, the control has to be such that the mixture is always an explosive one. With each kind of gas used in an engine there are both higher and lower limits to the amount of air with which it may be mixed if it is to remain an explosive mixture. If the ratio of air to gas should be outside these limits, the mixture sent to the exhaust would be unburned and valuable gas would be lost. Conseqently, if the engine goes above normal speed when admitting the weakest explosive mixture, the power of the engine has to be further reduced by omitting the admission of gas entirely. In Fig. 32 is shown a device for governing in the manner just described. The governor *d* is driven from the cam shaft *c* through the bevel gears shown in section. Gas is admitted by raising the end of the lever on which is a reel *b* similar to *c* in Fig. 31. The sleeve *a* is free to slide on a feather on the cam shaft *c*, its exact position being controlled by the governor through the bell-crank lever *e*. On the sleeve *a* is a series of cams of the same throw but of different circumferential lengths. The duration of the admission of gas is varied by shifting the sleeve so as to bring different cams into engagement with *b*. In the position shown the engine is above normal speed, and the sleeve is at extreme position to the right and no gas is being admitted. As the speed of the engine falls, the sleeve travels to the left, admitting gas for a definite period for each engine speed. With full load on the engine, the reel engages with the longest cam and the strongest mixture is admitted to the cylinder.

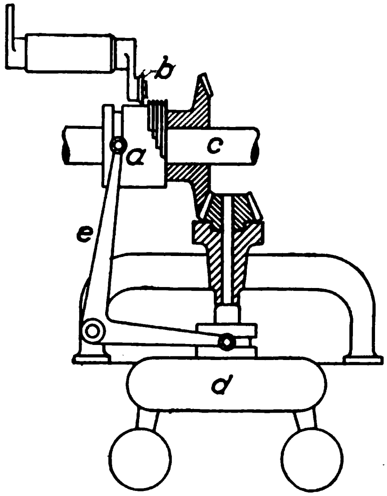


Fig. 32. Diagram of Governor.

With this method of governing, the same amount of the mixture is always taken into the cylinder, and consequently the pressure at the end of compression is always the same. The explosion, however, becomes weaker as the mixture is "leaner" and requires a longer time for its completion. A comparison of the areas of Figs. 20 and 21 shows the effect of a weaker mixture on the power of the engine.

It is found in practice that there is a certain strength of the explosive mixture which gives the most economical running of the engine. It is obviously desirable to run the engine with a mixture of this strength, and that can be done when a hit-and-miss governor is used. When it is desired to have an impulse every cycle, a constant strength of mixture can be maintained if the power of the engine is controlled by varying the *amount of the mixture* taken in. An example is shown in Figs. 33 and 34 of the actual mechanism used for this purpose. Gas from the passage

G enters a port in the cylindrical valve A and meets air which enters from D through similar ports. The mixture passes out of the valve through a large port near the top and goes through C to the cylinder when the inlet valve D is open. The relative amounts of gas and air are regulated by the two levers H H, which are connected to entirely independent cylindrical shells inside the valve A and which can rotate them so as to cover up more or less of the lengths and therefore of the areas of the gas and air ports respectively. With the two levers in constant positions the areas for admission of gas and air to the cylindrical valve A will be fixed, and consequently the strength of the mixture will be constant. The actual amount of the mixture entering the cylinder is controlled by the governor B, which works an internal cylindrical valve in such way as to throttle the discharge port of the valve A when the speed increases.

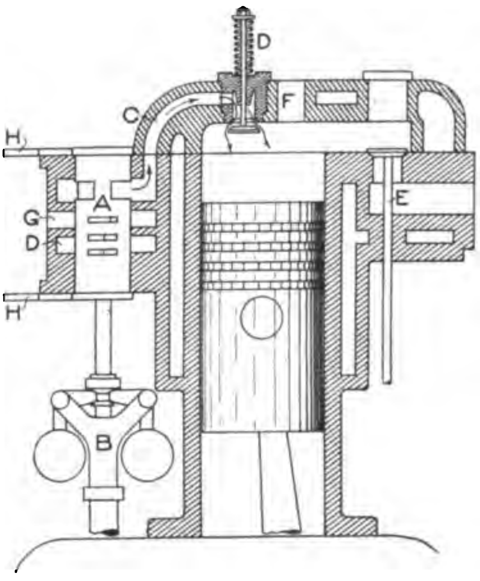


Fig. 33. Mixing Valve of Westinghouse Engine.

This method of governing permits a perfect adjustment of the work done in the cylinder each cycle, and consequently gives more uniform speed of the engine than any of the methods so far described. The throttling of the mixture imposes extra work upon the engine during the admission stroke, as the piston has to move out with a vacuum behind it. At the end of the admission the pressure in the cylinder will be less and less as the load on the engine becomes smaller, and consequently the pressure in the cylinder at the end of compression is less as the load decreases. With decreased compression the combustion of the mixture is slower. This is well shown in Fig. 35, which gives a series of indicator cards taken at different loads from an engine using a strong mixture and a throttling governor.

Another method of accomplishing the same result is to admit a mixture at atmospheric pressure for part of the admission stroke only, the duration of the admission being determined by the governor. This method of governing gives an indicator card similar to Fig. 19. The difference between an engine governing in this way and one governing by the throttling method is similar to that between a Corliss steam engine and a throttling steam engine. The advantage of *cut-off* governing is in the decreased work done by the engine in drawing the charge into the cylinder. The use of a partial charge, whether obtained by throttling or by cutting-off, permits the expansion of the exploded mixture to a lower pressure than is possible in an engine admitting a full charge and having the same pressure at the end of compression. This is the practical method of obtaining the increased expansion, the advantage of which has been already pointed out.

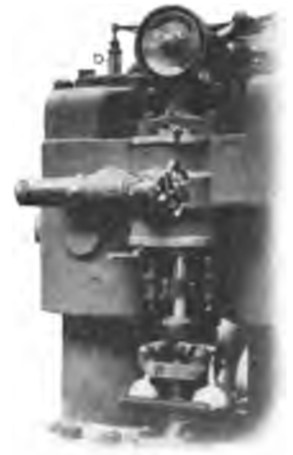


Fig. 34. Governor of Westinghouse Engine.

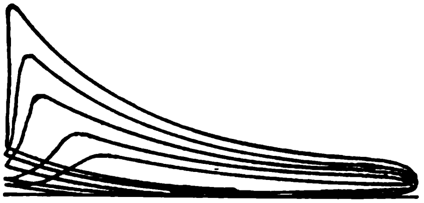


Fig. 35.

When economy is not of the greatest importance, as, for instance, in automobile practice, the power of the engine may be controlled by *varying the point of ignition*. It has been shown already (Fig. 22) that the power of the engine decreases as the lead of the ignition becomes less. If the ignition occurs after the beginning of the stroke, the lead is said to be negative, and the power is greatly decreased. If the lead is increased (Fig. 23), there still results a decrease of power. The control of the power by varying the ignition is always uneconomical, but the method is one of extreme simplicity.

Starting. A gas engine will not start itself in the way a steam engine does when steam is turned on. It is necessary to get the engine in motion by means of some special source of power before it can take up its normal cycle of operations. Generally this special source of power is not adequate to get the engine moving rapidly when it is connected to any considerable load; it is always preferable and generally necessary to throw the load completely off the engine till it gets under way.

In the normal running of an engine the ignition of the charge occurs before the end of the back stroke, and if the time of ignition is kept the same when starting there is a danger, or often the certainty, that the high pressure of the explosion acting on the piston before the crank has got to its dead center, will overcome the inertia of the engine, which is small because of its low speed, and will reverse its direction of rotation. If the starting power is small, the ignition has to be retarded by some special device so that it will not occur till after the crank has passed its dead center —that is, there must be negative lead. An example of a device for retarding the ignition is given in Fig. 36. The igniter rod A (compare with *f*, Fig. 28) which is worked by a crank on the side shaft B, is supported during normal running on the reel C, which is loose on the fixed spindle D. In the position shown it is just about to trip the interrupter lever E on the spindle which moves the movable electrode. When starting, the reel C is slid along the spindle D so that the igniter rod A rests, as shown in the dotted lines, directly on D, consequently the tripping occurs so much later.

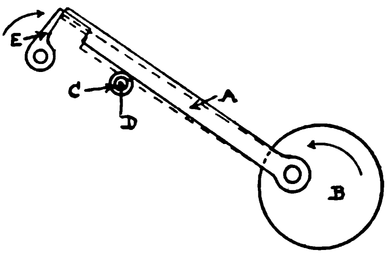


Fig. 36.

There are several general methods of starting gas engines. If the engine is small, not exceeding 10 H. P., and can be disconnected from its load, it is common to start it by turning it over by hand for a few revolutions till an explosive mixture is admitted and ignited. As it is difficult to pull the engine over when the charge is compressed for the whole back stroke, most engines are provided with an extra exhaust cam which is put into action while starting, and which not only opens the exhaust valve during the exhaust period but also opens it again during the first part of the compression period, so that some of the explosive mixture is forced out of the cylinder and the amount of compression is decreased. The explosion of this diminished charge after the crank has passed the dead point, starts the engine going, and after operation under these conditions for several cycles, the engine will come up to speed if it is not loaded heavily, and the compression and ignition may then be changed back to the normal running conditions.

With large engines it is impracticable to start by hand, and other devices have to be used. One of the most simple and certain is to start the engine by the admission of compressed air, which acts on the piston just as steam does in a steam engine. This method is especially desirable in an engine with several cylinders, in which case one cylinder is used as a compressed air cylinder to run the engine till the other cylinders take up their normal cycle of operations; and then the compressed air is shut off and the first cylinder is put into normal action. If the engine has only one cylinder, it can be brought to a good speed by the admission of compressed air, and then, after the compressed air is shut off, it will continue to revolve by its own inertia until an explosive mixture is taken in and exploded.

An arrangement for starting a multicylinder engine with compressed air is illustrated in Figs. 3 and 37. A compressor (Fig. 37), which is driven by a belt from the engine, forces air into a storage tank and brings it to a pressure of about 160 lb. In case of need the compressor can be operated by hand. When the engine is to be started, the compressed air can be admitted to one of the cylinders. The cam B (Fig. 3) on the upper shaft is first thrown out of action by a special device, so that the inlet valve J cannot open. The hand lever on the outside of the crank case near the cam A is thrown over, putting the ordinary exhaust cam A out of action, but bringing into action a double cam which keeps the exhaust valve E open throughout every up-stroke of the engine. Another cam on the same shaft is brought into action at the same time, and operates a starting valve (not shown) on the pipe from the compressed air reservoir, admitting compressed air to the cylinder on every down stroke. The cylinder then acts as a compressed air engine till the explosions begin in the other cylinders, when the cams B and A are brought back to their normal positions and the starting cylinder functions normally. In other engines compressed air is admitted to the cylinder during the expansion stroke by manual operation of a special valve. After two or three admissions during successive cycles, the engine will attain speed enough to permit the opening of the gas valve and the commencement of the cycle.

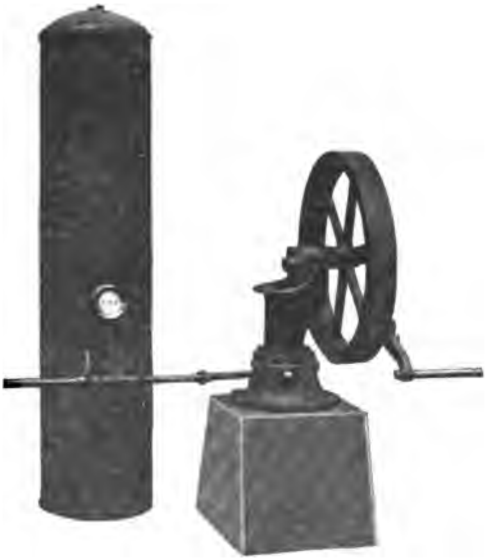


Fig. 37. Air Compressor.

With engines up to 100 H.P. a common method of starting is to ignite a charge which has been drawn into the engine by turning it over by hand. The engine is brought to the beginning of the expansion stroke, and a definite amount of gasoline is put into a cup which connects with the cylinder through a valve which is opened. The engine is then pulled over till the piston has made half its forward stroke, air being drawn in and forming an explosive mixture with the gasoline which enters at the same time. The gasoline valve is then closed and the engine is turned quickly in the opposite direction, the charge is compressed as much as possible, and is then ignited. The ignition is brought about by tripping the electric igniter by hand, or by the use of a special detonator, or even, in some cases, by striking a match inside the cylinder by means of a special device. It is not possible with a loaded engine to compress the charge much by hand, so that this method is only applicable to engines of moderate size which can be disconnected from their starting load.

If the engine has to start under moderate load, it is generally necessary to supply the engine with a charge which has been compressed to a high pressure. This can be accomplished by setting the engine with the crank about ten degrees past the dead center on the expansion stroke, and then pumping an explosive mixture into the cylinder (Fig. 38) till the piston begins to move. At that instant the charge is ignited, and the work done by the expansion of the exploded charge will be enough to start the engine on its cycle of operations. Another method of accomplishing the same thing is to connect the cylinder E (Fig. 39) with a special starting chamber D. When the engine is being shut down, the special inlet valve A is lifted from its seat, so that at each suction stroke air is drawn through the chamber D by way of the valve F. The chamber D, the cylinder, and the connecting pipe are thus filled with pure air at atmospheric pressure. When the engine is to be started the gas cock C is opened and gas flows both into the chamber D and into the cylinder, a cock on the cylinder being opened. A pilot light burns across the opening above the valve F, and after a

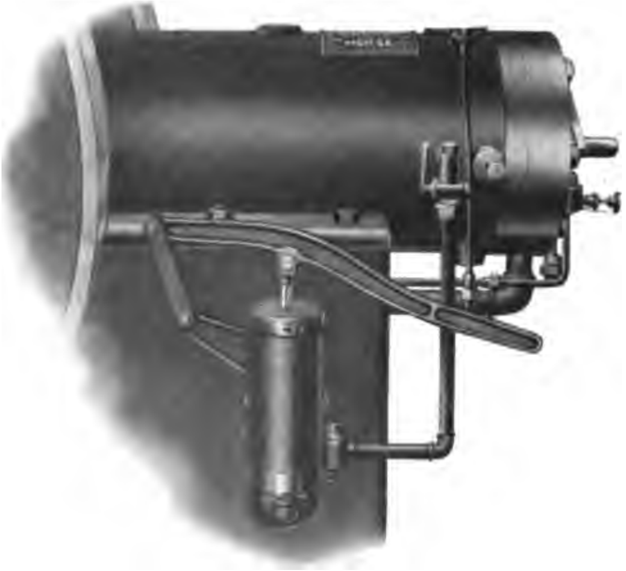


Fig. 38. Starting Gear of the Fairbanks-Morse Engine.

short time a combustible mixture of air and gas issues and catches fire. If the cock C is then closed, the flow of the explosive mixture stops and the flame consequently shoots back past the valve F and ignites the mixture in D, closing the valve F against an upper face by the force of the explosion. The flame proceeds to the cylinder, the contents of which will have been compressed by the explosion in D, and causes an explosion there. In large plants a special starting engine is customary.

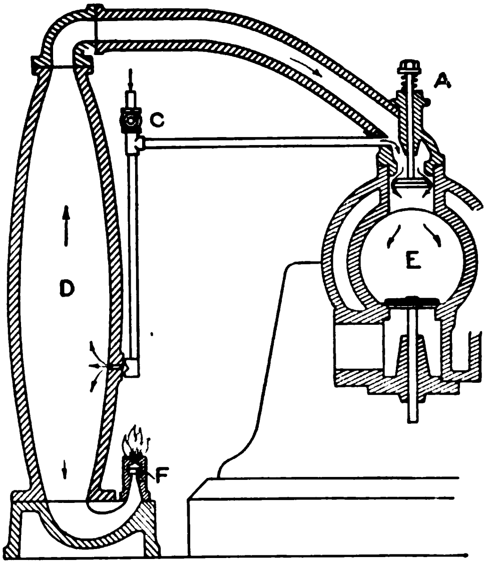


Fig. 39.

Water Jacket. In all the preceding sectional views of gas engine cylinders it will be seen that the cylinder barrel and the cylinder head have double walls and in every case provision is made for the active circulation of water through the space between the two walls. Without the use of a *water jacket*, or some equivalent device, the engine would be inoperative, because the high temperature to which the cylinder would be raised by the explosions would not only vaporize the lubricating oil and cause the rapid destruction of the cylinder, but also the entering mixture would be exploded before its time by contact with the hot metal. The necessity for effective cooling is greater in the larger engines; it is often necessary to water-jacket the exhaust valve in large engines that it may not be warped out of shape by the high temperature, and may not be hot enough to ignite the entering charge. The cooling arrangement for a balanced exhaust valve is shown in Fig. 14, the water entering the valve through the tube *b* and escaping after circulating at *c*. In some large engines the pistons also are water-jacketed. In very small engines it is possible, when the engine is placed in a strong current of air, to replace the water jacket by a system of thin metal ribs (Fig. 40), or points, on the external surface of the cylinder. The current of air can be obtained either from a fan driven by the engine, or, as in bicycle motors, by the movement of the engine itself. When the engine is water-jacketed it is often practicable with small engines to use the same cooling water over and over again, and there is a distinct economy in so doing when the water must be paid for. The usual arrangement (Fig. 41) consists of a vertical galvanized iron water tank of considerable capacity connected at its bottom to the lower part of the jacket, and near its top to the upper part of the jacket. The water in the jacket being heated, rises and flows to the upper part of the tank, where it cools by contact with the air and with the sides of the tank. Cold water from the bottom of the tank flows to the cylinder jacket to take its place. A continuous circulation is maintained by the difference of density between the cold and the heated water. In large engines when a large amount of water must be circulated, this method is generally too cumbrous and the water is taken from some constant source of supply, such as the city mains. The piping and valves are always so arranged that it is possible to draw the water from the jacket.

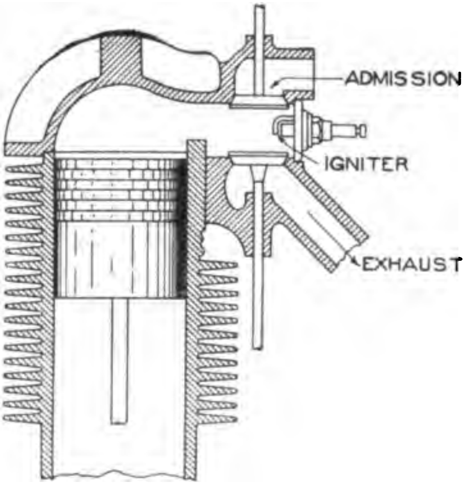
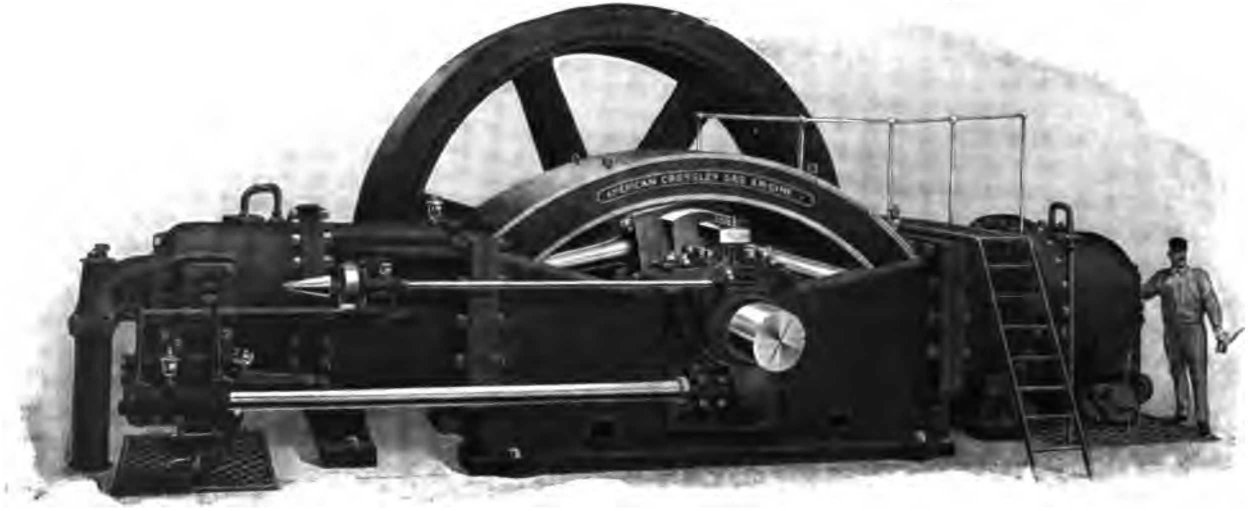


Fig. 40. Arrangement of Cylinder for Air Cooling.

The Explosive Mixture. The air used in the engine may be taken from the engine room or from the outside. The inrush of air to the air pipe makes a noise which is often objectionable in the engine room, but which can be greatly reduced if the air is taken from a large chamber, as in Fig. 10, where it is taken from the base of the engine.



AMERICAN CROSSLEY GAS ENGINE.
Power and Mining Machinery Co.

If the gas is taken from the city mains, the intermittent action of the engine in admitting gas will cause considerable fluctuation of pressure in the supply pipe, which is not only undesirable in that it makes variable the amount of gas admitted, but also causes flickering of any lights supplied from the same pipe. To reduce this fluctuation it is usual to insert in the gas supply pipe a rubber bag (see Fig. 11), which collapses partly during the admission stroke and fills out again during the other strokes. Any enlargement in the gas supply pipe will serve the same purpose, but the flexible rubber bag is more effective than a mere enlargement.

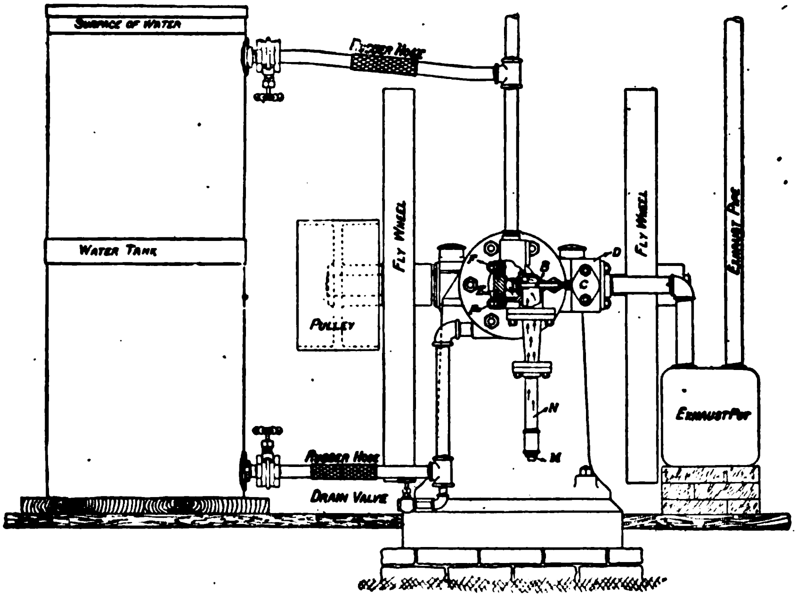


Fig. 41. Arrangement of Water Circulation for Jacket.

The air and gas should be mixed as thoroughly as possible on their way to the cylinder. This is satisfactorily accomplished if the air and gas have to pass through a common admission valve after they are mixed, as in Figs. 8, 10 and 33. The strength of the mixture is adjusted by throttling the gas supply, the air supply being left uncontrolled.

The Exhaust, if allowed to escape direct from an exhaust pipe of uniform cross section, is generally a source of annoyance by reason of the loud noise which it makes. This noise is greatly reduced if the pipe discharges into an exhaust chamber or pot (see Fig. 41) before going to the air. The injection of water into the exhaust pipe is also useful in reducing the noise in large engines. To make the noise nearly imperceptible a good plan is to have the pipe discharge near the bottom of a pit filled with large stones.

Modifications of the Otto Cycle. Although the gas engine using the Otto cycle will give a higher efficiency than any steam engine, it is nevertheless desirable to increase its efficiency as much as possible. Its efficiency has been shown to depend on the amount of compression, and the obvious way of increasing the efficiency is to decrease the clearance and thereby increase the compression pressure. The amount of compression that can be used is limited by two considerations. The first is that it is not commercially practicable to construct engines which will work properly under very high pressures rapidly imposed by explosions. With an engine compressing the charge to 100 lb. pressure and using a strong explosive mixture, the pressure in the cylinder rises suddenly to about 350 lb., and this is at present about the practicable limit. If the explosive mixture is weak, the compression may be increased; with very weak mixtures a compression to 200 lb. is sometimes used, and results in a maximum pressure of about 300 lb.

The second objection to the use of high compression is that the rise in temperature of the mixture resulting from the compression may easily be sufficient to explode the mixture before the piston has reached the end of its stroke. Such pre-ignition of the charge, tending to force the piston back, gives rise to a great shock and is very destructive to the engine, besides reducing its efficiency, and is consequently to be avoided. Pre-ignition may occur even with low compression if any part of the clearance is not water-jacketed, or if there is any metallic projection into the clearance space. Such unjacketed parts, or projections, not being properly cooled, are liable to be raised to a temperature high enough to cause the ignition of the charge. This often forces water-jacketing of the exhaust valve and of the piston in engines of large size.

Another method of increasing the efficiency is by what is known as *scavenging* the cylinder. In the ordinary Otto cycle the charge which is compressed consists of a mixture of fresh air and gas with the burned gases remaining in the clearance space from the previous cycle. If these burned gases are expelled from the cylinder by a charge of fresh air before the admission of the explosive charge, the force of the explosion and the efficiency are increased. The clearing out or scavenging of the cylinder with fresh air has been accomplished in several ways. The simplest method is by the use of an exhaust pipe of such length that the gases exhausting from the cycle with great velocity create a vacuum in the cylinder near the end of the exhaust stroke. This vacuum causes the automatic air admission valve to open and the consequent rush of air from the air valve to the exhaust port flushes out the cylinder, especially if the air and exhaust valves are on opposite sides of the clearance space. Occasional scavenging is obtained in engines governing on the hit-and-miss principle, each idle cycle flushing out the cylinder with the result that the succeeding explosion is of greater force than the normal explosion.

It has been pointed out already that the pressure at the end of the expansion in the Otto cycle is high, and that the efficiency of the cycle can be increased considerably if the gas is expanded more completely. Ordinary steam engine practice suggests that the more complete expansion can be obtained by *compounding*, but attempts so far to make a satisfactory compound gas engine have not proved very successful. The practical method of obtaining more complete expansion is to take into the cylinder a diminished charge. The two methods of accomplishing this have been discussed already. The only fundamental difference between engines using these two methods is that in one case the governor controls the amount of the opening of the admission valve, while in the other case it determines the instant at which the admission valve shall close.

One of the main objections urged against the Otto cycle is that it requires two revolutions of the engine for its completion, so that the expansion or motive stroke comes but once in four strokes. There results from this a very irregular driving effort, making large fly wheels necessary if the main shaft is to rotate uniformly, or else requiring the use of several engines working on the same shaft. The motive efforts can be made twice as frequent if the cylinder is double acting, with admissions and explosions occurring on both sides of the piston. Many large engines are now being made double acting, but the practical troubles in keeping the piston, piston rod, cylinder and stuffing box cool enough for satisfactory working have prevented the use of double-acting cylinders in engines of small size.

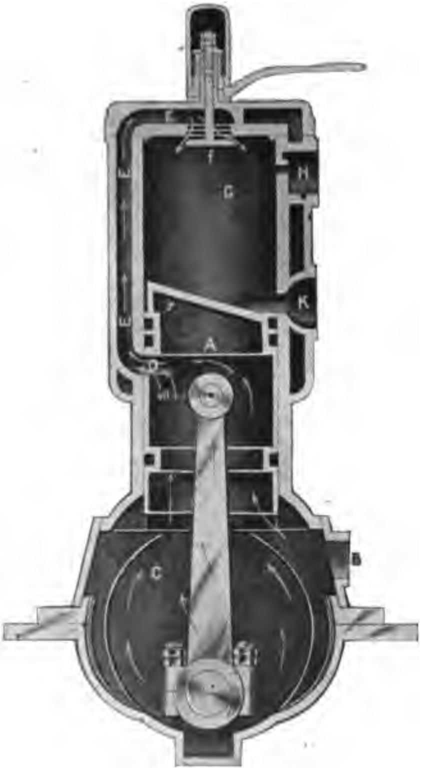


Fig. 42. Smalley Two-Cycle Engine.

An increased frequency of the expansion or motive stroke can be obtained by a slight modification of the Otto cycle which results in the cycle being completed in two strokes, and which is consequently called the *two-cycle* method. Engines using the two-cycle method give an impulse every revolution, and consequently not only give greater uniformity of speed of rotation of the crank shaft, but also develop nearly twice as much power as *four-cycle* or Otto cycle engines of the same size. Moreover, they are generally of great simplicity, having fewer valves than the four-cycle engines. An example is shown in Figs. 42 and 43 of a two-cycle engine of small size; Fig. 42 is a vertical section showing the piston at the bottom of its stroke, and Fig. 43 is a vertical section in a plane at right angles to the previous section plane and showing the piston at the top of its stroke. As the trunk piston A makes its upward stroke, it creates a partial vacuum below it in the closed crank chamber C, and draws in the explosive charge through B. On the downward stroke the charge below the piston is compressed to about 10 lb. pressure in the crank chamber C, the admission through B being controlled by an automatic valve which closes when the pressure in C exceeds the atmospheric pressure. When the piston reaches the lower end of its stroke, it uncovers the exhaust port K and at the same time brings the admission port D in the piston opposite the by-pass opening E E E, and permits the compressed charge to enter the cylinder G through the automatic admission valve *f* as soon as the pressure in the cylinder falls below that of the compressed charge. The return of the piston shuts off the admission through E and the exhaust through K and compresses the charge into the clearance space. The charge is then exploded (Fig. 43) and the piston makes its down or motive stroke. Near the end of the down stroke, after the opening of the exhaust port K, the admission of the charge at the top of the cylinder sweeps the burned gases out, the complete escape being facilitated by the oblique form (Fig. 42) of the top of the piston. The engine is so designed that the piston on its return stroke covers the exhaust port K just in time to prevent the escape of any of the entering charge. The processes described above and below the piston are simultaneous, the upstroke being accompanied by the admission below the piston and compression above it, while the down stroke has expansion above the piston and a slight compression below it. The very short interval of time between the beginning of the exhaust and the admission of the new charge (which enters as soon as the pressure in the cylinder has fallen enough to permit the admission valve to open), makes premature ignition of the charge, or *back firing*, of not infrequent occurrence. If

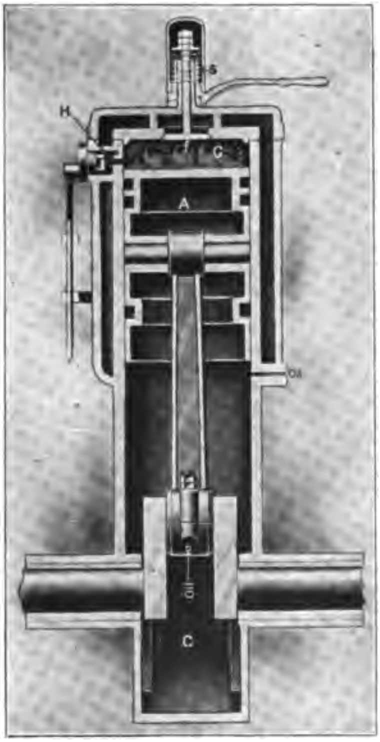


Fig. 43. Smalley Two-Cycle Engine.

the mixture is weak, or the speed is very high, so that the charge is still burning when the exhaust opens, or if the frequency of the explosions bring any part of the cylinder to a red heat, the charge will be ignited on entering, and the explosion then travels back through E E E to the crank case, which has to be made strong enough to resist it. In large engines the charge is compressed by a separate pump and not in the crank case. A modification of this engine makes the construction even more simple, so that the only valve on the engine is the automatic valve admitting the charge to the crank case. In this engine (Fig. 44) the series of operations is precisely similar to that just described. The only difference is in the by-pass connection E, which has no valve between it and the cylinder. The exhaust is made to open a little earlier than the admission, so as to make sure that the pressure in the cylinder shall have fallen below the pressure of the slightly compressed charge when the admission port opens. If the opening of the exhaust and admission ports were simultaneous, as in the engine just described, some of the exhaust gases would force their way through E to the crank case, igniting the charge there. The piston is so shaped that the entering charge is directed to the top of the cylinder, forcing out the burned gases before any of the charge can escape through the exhaust port.

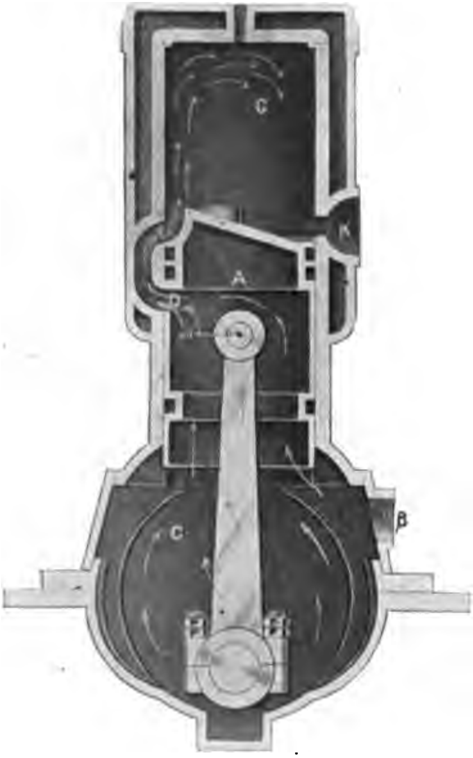


Fig. 44. Smalley Two-Cycle Engine.

The fact that the exhaust port is open while admission is taking place makes it always possible in a two-cycle engine that some of the charge may be lost through the exhaust. If the exhaust closes early, so as to diminish the probability of such loss, it will cause the retention in the cylinder of an unnecessarily large volume of burned gases, with consequent decrease in power and efficiency. The two-cycle engine may then be regarded as a modification valuable from the point of view of the more uniform turning movement, compactness and simplicity, but it is always likely to be inferior in efficiency. In some large engines the air and the gas are compressed separately; air alone is admitted at first, expelling the exhaust gases, and then the gas valve opens, admitting gas with the air. In this way the cylinder can be thoroughly scavenged and the exhaust be closed before any of the explosive charge reaches it.

Gas Engine Fuels. The fuels used in gas engines are very variable in origin, in composition, and in heat value. They consist almost entirely of various compounds of the chemical elements of carbon, hydrogen and oxygen, diluted with more or less nitrogen. In those regions where *natural gas* occurs, that fuel is used almost exclusively in the gas engine; but in most regions the gas has to be made either from solid or from liquid fuels. The use of liquid fuels will be considered later in connection with the discussion of the oil engine. In most towns of moderate size there is available *illuminating gas* made from coal. The illuminating gas is made by one of two processes giving either *coal gas* or *water gas*.

Coal Gas is made by heating the coal in a retort away from contact with the air, so that no combustion takes place. The hydrocarbon gases in the coal are driven off by the heat, and after undergoing various purifying processes, are collected in a holder. The non-volatile part of the coal remains as coke. The gas consists mainly of hydrocarbons and has a high heating value.

Water Gas is made from a non-gaseous fuel such as anthracite coal or coke, by an intermittent process. Air is blown through a bed of coal several feet thick until the coal is incandescent, the products of combustion being permitted to escape. Then a jet of steam is blown through the incandescent fuel, and is thereby broken up into its constituent elements—hydrogen and oxygen.

The oxygen combines with the carbon of the fuel to form carbon monoxide, CO; the hydrogen goes off unchanged. The passage of the steam quickly cools the coal, and air has to be blown through again. The only gas collected is that generated during the steam blow; it consists principally of hydrogen and carbon monoxide, and has a much lower heating value per cubic foot than coal gas. The whole of the coal is consumed in this process.

Both coal gas and water gas are excellent fuels for use in a gas engine, but as they have gone through certain processes for cleansing them and increasing their illuminating power, which increase the cost of the gas but do not add materially to its value for gas engine use, and since also the cost to the consumer is considerably greater than the cost of production, they are not economical fuels. Such fuels should be used only when the engine is very small or its operation very infrequent.

For engines of 50 H.P. or over, which are in regular operation, it is practically always more economical to generate the gas in a special *gas producer* than to use illuminating gas. In the gas producer either air alone, or generally both air and steam, are sent through a thick bed of coal. The oxygen of the air on first striking the zone of the incandescent coal combines with the carbon to form carbon dioxide, CO_2, but this on passing through the burning coal above, is reduced to carbon monoxide, CO, which escapes with the hydrogen and carbon monoxide resulting from the action of the steam on red hot coal, and with the nitrogen which came in with the air. The resulting gas therefore consists almost entirely of carbon monoxide, hydrogen and nitrogen. The large amount of nitrogen in the air (79 volumes in 100) makes the producer gas contain fifty per cent or more of that inert gas, and consequently gives it a low heat value.

A good example of a gas producer is shown in Fig. 45 under working conditions. The bed of coal, several feet thick, rests on a bed of ashes of about equal thickness, the ashes being supported on a solid circular table *a*. The blast pipe *b* terminates near the top of the bed of ashes, the blast being discharged radially so as not to concentrate the combustion. The blast is generally produced by a steam jet blower, but sometimes a fan blower is used. In the latter case steam is mixed with the air in the blast pipe so as to keep down the temperature of the producer and to soften any clinkers that form. Fresh coal is supplied by a continuous automatic feeding device on top of the producer, which spreads the coal in a uniform layer over the upper surface. In many producers the coal is merely dumped in from above at intervals, and has to be spread by hand. The intermittent charging has the disadvantage that it causes considerable variation in the condition of the fire, and consequently in the composition of the gas generated. The bed of ashes is maintained of the desired depth and the surplus ashes removed by rotating the grate *a* by means of gears worked through the crank *c*. As the grate is placed at some distance below the conical casing or *bosh*, the ash discharges uniformly around its periphery when it is revolved. This causes a uniform settling of the bed of ash, and also lets the bed of fuel settle so as to close up any channels in it which have been formed by the blast. The scrapers *d*, projecting a short distance into the ash bed, help the discharge of ash from the grate. The depth of the bed of ashes ensures that the ash is completely burned and cooled before it is finally discharged.

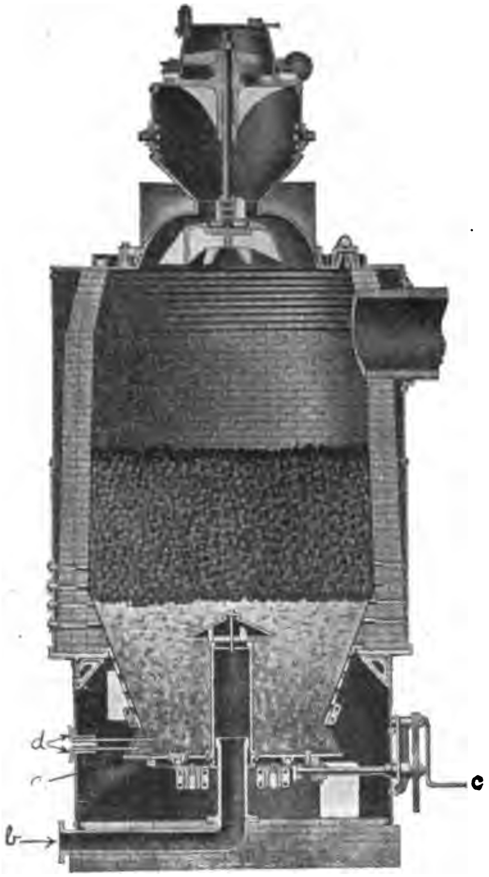


Fig. 45. Taylor Gas Producer.

Producer Plants are of two kinds, according as the flow of air through the producer is caused by air being forced in from below or by a partial vacuum being created above the fuel. The former is called a *pressure plant*, the latter a *suction plant.*

The general arrangement of the *pressure type* of producer gas plant is shown in Fig. 46, in which the arrows indicate the direction of flow of the gas. A small boiler supplies steam to the blower. The gas escapes from the producer at a high temperature and goes to an economizer, where it gives up much of its heat either to fresh air, which is about to be forced through the producer, or else to water, the vapor from which mixes with the air. The gas then passes to the scrubber, where it meets a spray of cold water, which further cools it and takes from it dust and solid impurity, after which it goes to the purifier for the extraction by chemical process of certain undesirable components and for the completion of the removal of solids, and thence to the gas holder. If anthracite coal or coke are used, very little chemical purification is necessary; if bituminous coal is being burned, the cleaning is somewhat more complicated, as the tar and other troublesome substances in the gas have to be extracted before it can be used.

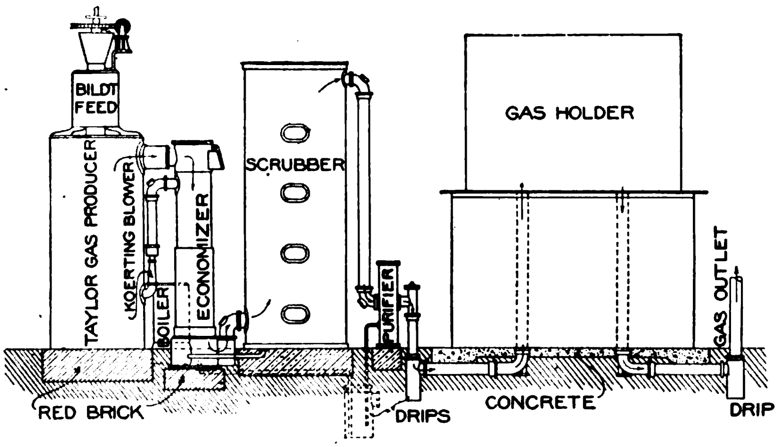


Fig. 46. Producer Plant—Pressure Type.

The *suction type* of gas producer plant can be used only when the operation of the engine is continuous for long periods. It has considerable advantage over the pressure type in compactness, but is rather troublesome to start. The flow of air and vapor through the fuel in the producer or generator (Fig. 47) is dependent on the sucking action of the engine each time it takes in a charge, so that no boiler is needed to produce the blast. The volume of gas generated is always equal to the amount that the engine uses, so that no gas holder is required between the producer and the engine, its place being taken by a small gas tank. To start the producer working, a small hand or belt-driven blower is used, and the products of combustion are sent past a by-pass valve directly to the atmosphere until the escaping gas will burn steadily. The by-pass valve is then closed, and the gas is forced through the scrubber

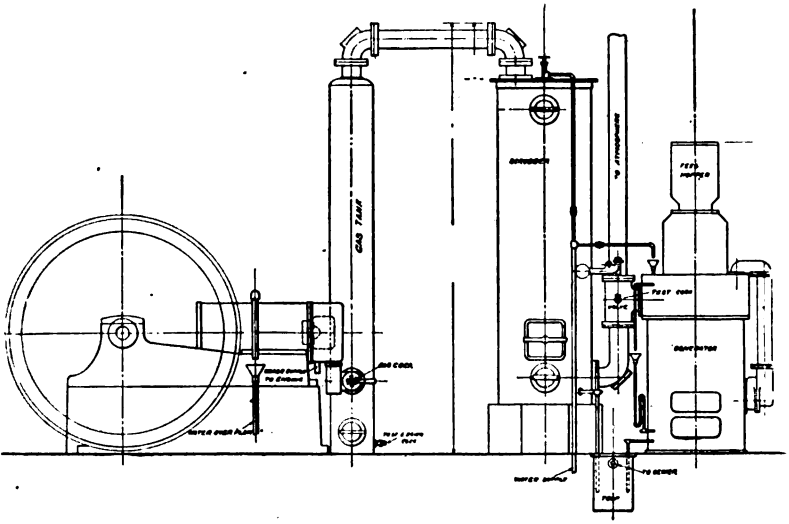


Fig. 47. Producer Plant—Suction Type.

and purifier into the gas tank and the whole apparatus is filled with gas. When good gas appears at a test cock near the engine, the engine is put in operation and the blower is stopped, its function being performed thereafter by the engine. The hot gases escaping from the generator go first through an economizer or vaporizer (not shown in Fig. 47), and the steam formed there is conducted to the under side of the grate of the producer and is sucked through with the air.

Owing to the resistance offered by the fuel, scrubber, and other parts of the plant to the passage of the gas, its pressure on reaching the engine is considerably below the atmospheric pressure. This causes a decrease in the weight of the charge taken to the engine, and so makes the power of the engine less than when pressure gas is used. In order to get the high compression which is necessary to ensure ignition with a weak gas supplied at a low pressure, the clearance in the engine using suction gas is smaller than in other engines using the same cycle. It is not safe to use such an engine with illuminating gas, as the pressures resulting from explosion would be excessive. When in some cases illuminating gas is used to start the engine, a special device is used to exhaust some of the charge during the compression period, and so to reduce the compression pressure.

An efficient producer of either the pressure or suction type will waste not more than fifteen to twenty per cent. of the heat of combustion of the coal in converting it into gas—that is, the gas on burning will give up eighty to eighty-five per cent. of the heat of combustion of the coal. Its efficiency exceeds that of a steam boiler. If the gas produced is a weak one, it is produced in greater volume, and it has to be mixed with a much smaller volume of air than is required for illuminating gas. For example, ordinary coal gas must have at least six parts of air to one of gas, whereas producer gas requires a minimum of about one-and-a-quarter parts of air to one of gas.

The heat liberated by the combustion of a cubic foot of each of the gases discussed is as follows:

Natural gas.............	900 – 1000	B.T.U.
Coal gas	650 – 700	"
Water gas	300	"
Producer gas.............	120 – 150	"

The power which can be developed in an engine does not depend upon the heat of combustion of a cubic foot of the fuel but on the heat of combustion of a cubic foot of the explosive mixture. The difference in the amounts of air necessary for combustion with the different gases makes the heats of combustion per cubic foot of the explosive mixture much more nearly equal than the heats of combustion per cubic foot of the fuel. Thus, when mixed with just sufficient air for complete combustion, natural gas, coal gas, and water gas will all give up about 90 B.T.U. per cu. ft. of the explosive mixture, while producer gas gives up about 65 B.T.U. An engine will consequently develop about the same power whether using natural gas, coal gas or water gas; with producer gas it will develop considerably less power.

Blast Furnace Gas. Besides the gases produced from solid fuels for illuminating or power purposes, there are waste gases escaping in many industrial processes (notably in the production of pig iron) which have considerable heat value. These gases have been utilized by burning them under a boiler for the generation of steam, but they are generally satisfactory, after cleansing, as fuels for a gas engine, and when so used give three or four times more power than when used for steam generation. The gases escaping from a blast furnace have a heat value of about 100 B.T.U. per cubic foot. Even when the gas is so poor that it will not burn under a boiler, it can be made to burn satisfactorily in a gas engine because of the high compression to which it is subjected.

The Care of a Gas Engine. For the successful operation of a gas engine intelligent care and accurate adjustment are necessary, and also an understanding of the processes going on in the cylinder. It sometimes happens that the engine fails to start, although the ordinary starting operations have been carried out faithfully. The most common causes of this difficulty are incorrect strength of mixture, failure of ignition and leakage of the charge. The setting of the gas valve which gives a satisfactory mixture one day may give a non-explosive mixture on the following day as a result of variation of pressure of the gas or other change. The strength of the mixture should be varied in case of failure to start. If this is ineffective, the ignition should be tried. The batteries may have run down as a result of much use or of short circuiting, and should be tested by short circuiting momentarily, when they should give a bright spark. Too strong a current is undesirable, as it burns the contact points rapidly. It is well to have on hand a spare set of cells for putting in circuit. There should always be a switch in the battery circuit, which should be thrown out when the engine is shut down, so as to prevent short circuiting. If the battery is in good condition, the trouble may be with the electrodes, either by their having become fouled or wet, or, in the make-and-break system, by a gumming of the spindle of the moving electrode which makes it sticky and slow in action. The igniter plug should be withdrawn and the electrodes examined. The whole igniter circuit should be examined for short circuits.

If the trouble is not with the igniter it may be caused by leakage of the charge. To test this, the engine, if not too large, is pulled over by hand. The resistance to turning on the compression stroke should be very considerable. If the resistance is not very great, or decreases, the compressed charge is escaping. The leakage may be either past the piston, the igniter plug or the valves. If the leakage is past the piston, it is either due to the wearing of the cylinder or to the sticking of the piston rings. The latter is very liable to occur after a while, especially if the cylinder has been permitted to get very hot, and can be remedied by taking the piston out and loosening and cleaning the rings with kerosene. A leakage past the valves is due either to gumming of the valves or to other deposit which keeps the valve off its seat, to wearing of the valve, or to sticking of the valve stem in its guide as a result of imperfect lubrication. The gumming and wear of the exhaust valve is the most common of the causes of leakage and may be remedied by grinding the valve on its seat with flour of emery and oil.

The presence of water in the cylinder, which has leaked in from the jacket through imperfect joints, sometimes causes the electrodes to become wet and prevents the engine starting. In some engines the possibility of this particular trouble is avoided by a special design of the jacket which has no joints communicating with the inside of the cylinder.

The cylinder oil that is used in steam engines cannot be used in gas engines, as it carbonizes at the high temperature of the explosion, and forms a deposit in the cylinder and on the exhaust valve. A much lighter oil is used, and even this if supplied in excess causes a gradual accumulation of hard deposit in the cylinder which must be cleared out occasionally. Apart from its interference with the action of the igniter and exhaust valve, it is liable to cause premature ignition by being raised to incandescence.

Cold water must be kept circulating through the jackets whenever the engine is running, being started as soon as the cylinder warms up. A stoppage of this flow, even for a comparatively short time, is liable to have a disastrous effect upon the cylinder. A gradual accumulation of sediment may occur in the water jacket, with a consequent reduction in its efficiency. On shutting down, it is always better to drain the jacket, which not only prevents the possibility of its freezing up in winter, but also tends to clear it of deposit of sediment. Generally, however. the jackets are drained only in cold weather.

In the running of a gas engine—especially under light loads—very loud and alarming explosions are sometimes heard in the admission pipe or in the exhaust pipe. The *back firing* in the admission pipe nearly always results from a leaky admission valve. The explosions in the exhaust, indicating as they do the presence of explosive gases in the exhaust pipe, are caused either by the use of a mixture which is too weak or by faulty ignition. If the mixture is too weak, the charge taken in just after an explosion may fail to ignite because it is mixed with the products of the previous explosion, while the next charge taken in may explode because it does not mix with burned gas but with the weak charge in the clearance. The hot exhaust gases ignite the weak mixture which was rejected unburned to the exhaust at the previous cycle. If the ignition is imperfect, a good mixture may fail to explode and be exhausted, and then ignited in the exhaust pipe by the next exhaust of hot gases.

Large Gas Engines. A very rapid development has taken place in the size to which gas engines are built until they are now made as powerful as the largest steam engines. To obtain large powers and to get the desired uniformity of crank shaft movement, multi-cylinders and multi-cranks are commonly used. When double-acting cylinders are used, the piston being subjected to high temperatures on both sides, becomes too hot unless there is a circulation of cooling water within it. If the piston is to be water-cooled, the piston rod is made hollow and is furnished with an internal tube. A water pipe is attached to the piston rod near the crosshead, by means of swing joints, and a current of water flows through the internal tube to the piston, circulates through it in a regular path, returns along the annular space around the internal tube in the hollow rod and escapes through other pipes with swing joints.

To obtain an impulse each stroke from a single cylinder engine (Fig. 48) a two-cycle double-action engine may be used. In this engine the exhaust occurs by the uncovering of the ports in the middle of the cylinder when the engine is near the end of its stroke. The air and gas that are to be admitted are compressed separately in the cylinders B and A respectively. When in consequence of the opening of the exhaust, the pressure in the cylinder falls below that to which the air is compressed, air enters through the automatic valve D at the top of the cylinder, and rushing toward the exhaust port, sweeps the cylinder clear of burned gas. The gas admission valve opens immediately afterwards, and an explosive charge enters; but before this can get to the exhaust port, the return of the piston stops the exhaust. In this way the cylinder is kept clear of burned gases without the loss of any of the entering charge. The propagation of the explosion in the cylinders of large engines is comparatively slow, so that two or more igniters are sometimes used so as to start the explosion in several places simultaneously.

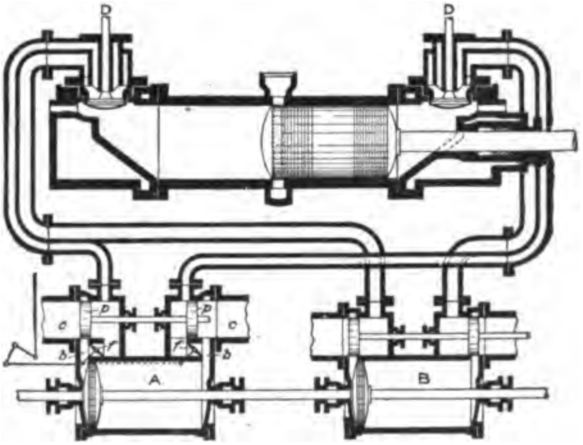
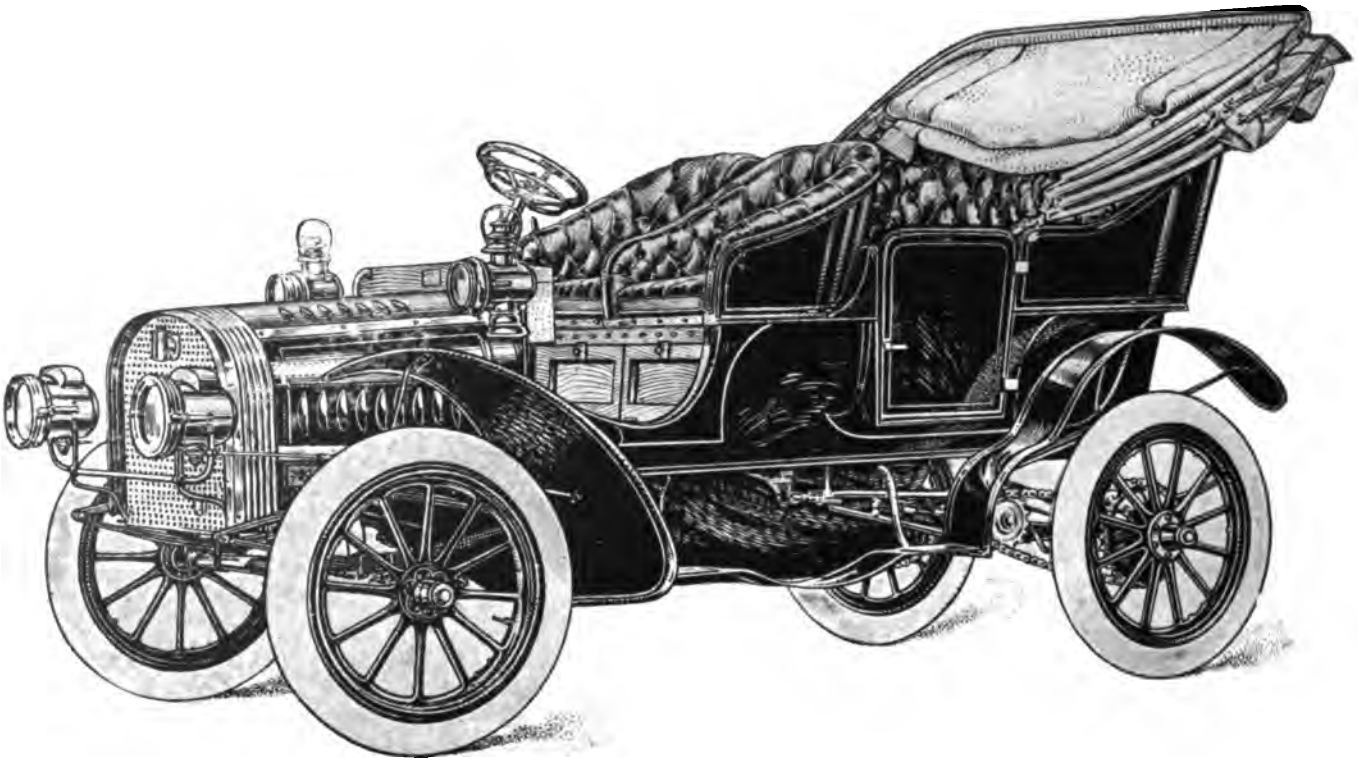


Fig. 48. Koerting Gas Engine.

Fuel Consumption. The consumption of fuel in a gas engine running at its rated load when natural gas is used, is from 13 to



SURREY TYPE AUTOMOBILE WITH 20 H.P. TWO-CYLINDER HORIZONTAL ENGINE.
Thomas B. Jeffery & Company,

17 cu. ft. per B.H.P. per hour; with coal gas 15 to 19 cu. ft. per B.H.P. per hour, and with producer gas about 1¼ lb. of coal per B.H.P. per hour. These are average good results; large engines show higher economy than smaller engines and have given a B.H.P. with a consumption of 1 lb. of coal per hour.

Oil Engines. The fuel used in oil engines is generally *crude petroleum* or some of the oils derived from it by the process of refining. Crude petroleum is not a simple chemical substance, but is a mixture of a very large number of different hydrocarbons having widely varying properties. If crude petroleum is slowly heated, it gives off as vapor its various constituent elements, the more volatile being given off at the lower temperatures, and the residue becoming continuously more dense and more viscous. In the refining of petroleum the vapors given off at various temperatures are condensed and collected separately, and the names given to the various products are an index chiefly to the temperature at which they give off their vapors. The most volatile of the ordinary products contains all the elements that vaporize at a temperature below 160° F., and is called *gasoline.* It gives off some of its lighter vapors at the ordinary temperature of the air, and as these vapors are highly combustible, gasoline is quite dangerous. When mixed with from eight to twenty parts of air, it forms an explosive mixture, which gives a more rapid explosion and consequently higher pressure than mixtures of equal heat value used in the gas engine. When exposed to the air, the lighter vapors escape, leaving behind a heavier and less volatile oil.

If petroleum which has been heated for some time at 160° is slowly raised in temperature to 250° F., a new and heavier series of vapors will be given off, which, when condensed and collected, are called *benzine* or *naphtha.* On still further raising the temperature from 250° F. to 350° F., a still heavier series of vapors is given off, forming the oil known as *kerosene.* Kerosene will not give off inflammable vapors till it is heated to about 120° F., so that it is comparatively safe and also will not change or deteriorate when stored under ordinary conditions. It is more difficult to burn satisfactorily than is gasoline, and when subjected to a high temperature with insufficient air for its combustion, it decomposes and deposits its carbon as a hard cake on the walls of the containing vessel. The dense petroleum which remains after the kerosene has been driven off is called *fuel oil.* If the fuel oil is subjected to still higher temperatures other and denser vapors are driven off, giving when collected *lubricating oils*, *cylinder oil* and *paraffine wax*, leaving finally a dense sticky mass which is known as *residuum.* The various oils can be distinguished in a general way by their densities, that is, their weights as compared with the weight of an equal volume of water. The density of gasoline is about .65, of kerosene about .80, of fuel oil about .82, of lubricating oils up to .92. If it is stated that an engine uses .76 kerosene, it means that the density of the kerosene is $\frac{76}{100}$ of that of water.

Crude petroleum, gasoline, kerosene and fuel oil are all used in oil engines. The cycle of operations through which the engine goes and the general structure of the engine may be the same for all these oils as for the gas engines already discussed; the only essential difference is in the addition of devices for supplying the oil to the cylinder and for its preparatory treatment.

Oil engines may be divided into two classes:

1. Those that convert the oil into a fine spray or a vapor before admitting it to the cylinder.

2. Those that deliver the oil to the cylinder in the liquid form.

Gasoline Engines. When gasoline is used, the vaporization is brought about by passing a current of air over or through the oil; the air escapes enriched with vapor of gasoline, and is said to be *carbureted.* The vessel in which the process takes place is called a *carburetor.* The carbureted air is too rich in fuel to be explosive, so that a further addition of air is necessary at the cylinder. The vaporization of part of the oil results in a lowering of temperature of the main body of the oil, and this reduces its volatility. In order to carry out the process satisfactorily with a uniform quality of the carbureted air, it is customary to heat the carburetor. This may be effected by making use of the heat either of the exhaust gases or of the escaping jacket water. The latter is more common with gasoline. A further advantage of moderate heating of the carburetor is that the denser constituents of the gasoline then become more volatile, so that the passage of the air through the oil does not result in depriving it of its lighter constituents and in leaving a residue too dense to be used.

The carburetor shown in Fig. 49 consists of a vertical cylinder surrounded by a water jacket. Gasoline is pumped to the top of the cylinder and, passing through a spraying device, falls in a finely divided state. It meets an upward current of air drawn in through inlets at the bottom by the suction of the engine cylinder. The carbureted air goes from the top of the carburetor to the engine, while any unvaporized gasoline drains to the suction side of the gasoline pump and is returned later to the carburetor. The water jacket has circulating through it some of the heated jacket water from the cylinder. The actual temperature of the jacket is controlled by a thermostat which varies the amount of water circulating.

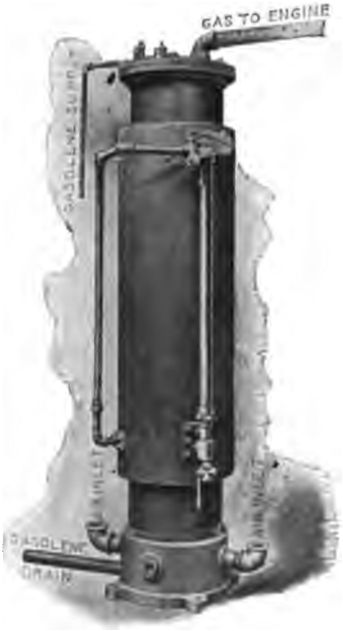


Fig. 49. Westinghouse Carburetor.

Gasoline is very fluid and atomizes completely when injected into a pipe through which a current of air is passing. The air in that case carries the gasoline with it, partly in the form of a mist and partly vaporized. This process is largely used in gasoline engines, and is illustrated in Fig. 50, which shows the whole arrangement of a gasoline plant. The gasoline tank is buried below the floor level and outside the building, so as to reduce the danger in case of fire or explosion, and also so that there can be no leakage of gasoline from the pipes when the engine is not running. The gasoline is taken through a strainer near the bottom of the tank and through the suction pipe by the action of a gasoline pump, which is worked from the cam shaft. It is then forced through the control valve A and is sprayed into the air pipe N through the jet H whenever the fuel admission valve G opens. A vertical branch of the discharge pipe from the gasoline pump has an overflow connecting with the tank. The pump always delivers more gasoline than is required, the excess being returned to the tank through the

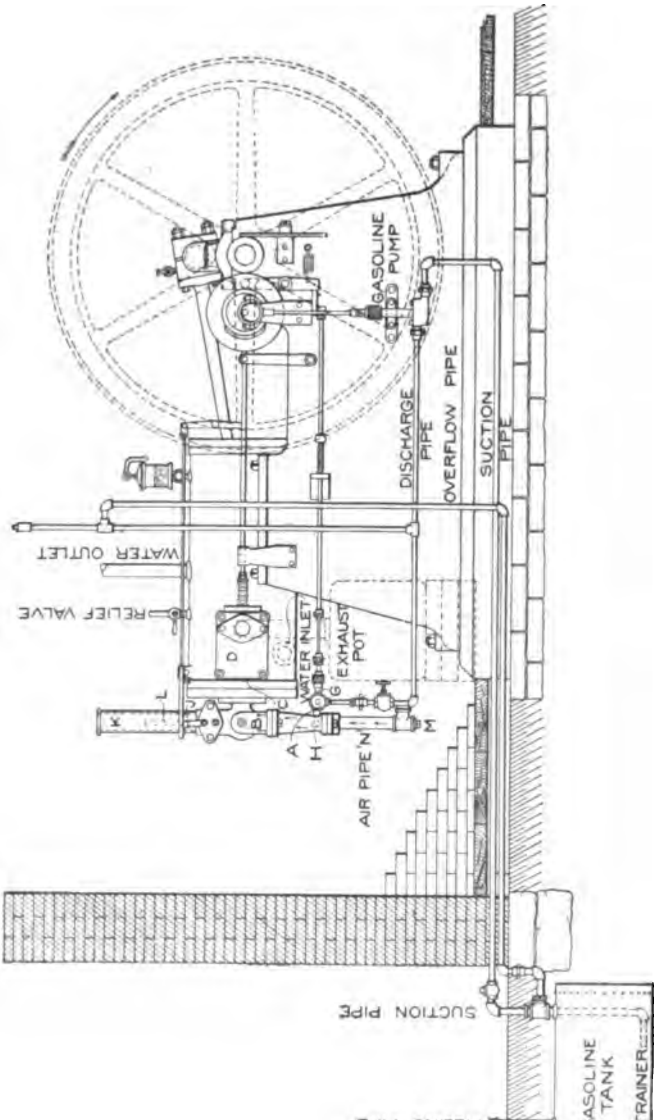


Fig. 50. Charter Gasoline Engine.

overflow pipe. This maintains a constant pressure of the gasoline depending only on the constant overflow level. With a given opening of the control valve A and a constant head on the gasoline, the amount of gasoline admitted each time remains constant.

An engine using gasoline is usually provided with a clearance space somewhat larger than that used in a gas engine, so as to prevent excessive pressures during explosion. The indicator card, Fig. 51, shows the rapidity and force of the explosion in a gasoline engine.

Kerosene and Crude Oil Engines. When kerosene or heavier oils are to be burned, different methods from those described for gasoline must be used. The kerosene is generally broken up in the carburetor into a fine spray or mist by a current of air; it is then sent to a vaporizer before being admitted to the cylinder. In the vaporizer the carbureted air is raised to a high temperature, the heat of the exhaust gases being utilized for this purpose, and the kerosene is converted into a vapor. Unless the kerosene is completely vaporized before admission to the cylinder, it is difficult to ensure its complete combustion. Some of the liquid kerosene in the cylinder *cracks* or breaks up into its elements as a result of the very high temperature to which it is subjected, and the carbon deposits itself on the piston and walls of the clearance space as a hard coating. The temperature in the vaporizer is not sufficient to crack the oil.

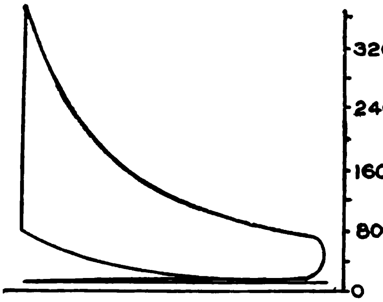


Fig. 51. Indicator Card of Gasoline Engine.

In some cases the carburetor or spraying device is omitted and the oil is pumped directly into a vaporizer or generator which converts the liquid into a vapor. A device of this kind for burning heavy crude oil, such as is found in the Texas oil fields, is shown in Fig. 52. The generator G is placed close to the engine so that the hot exhaust gases coming through the pipe N shall not be cooled before reaching it. The oil pumped by the engine goes through the pipe F to the small reservoir R on top of the generator, any excess returning by the overflow pipe O to the main supply tank. The amount of oil entering the generator is controlled by the throttle valve T at the reservoir R. The oil trickles down over surfaces which are heated by the exhaust gases and is partly or completely vaporized. Any unconsumed residue drains off through the cock D at the bottom of the generator. The temperature in the generator is regulated by a heat valve E, which may be set so as to circulate all or any part of the exhaust gases

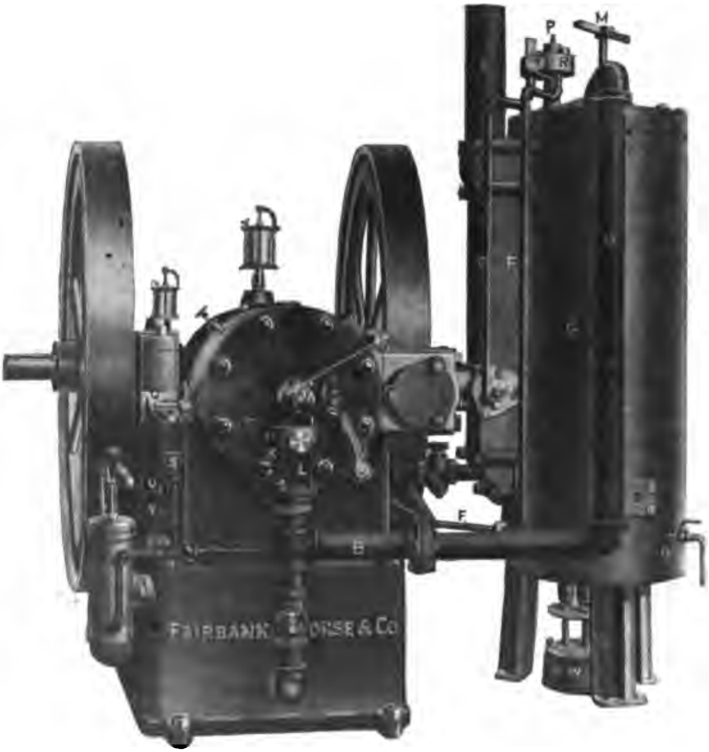


Fig. 53. Fairbanks-Morse Engine Arranged for Burning Heavy Crude Oil.

through the heating coil of the generator, the rest being sent directly to the exhaust pipe X. Air is drawn into the lower part of the generator through the pipe C, and the mixture of air and vapor leaving the top of the generator by the pipe B, meets a fresh supply of air arriving through the valve A before being admitted to the cylinder. When kerosene is to be used, the generator is very much smaller, but the general arrangement is similar.

Kerosene and the heavier oils can be used in oil engines without preliminary vaporization. One of the methods of accomplishing this is illustrated in Fig. 53, which is a longitudinal section of an engine using kerosene or crude oil. A combustion chamber or vaporizer A is attached to the end of the cylinder and communicates with it through a narrow neck B. The outer part of the vaporizer is unjacketed, and consequently is kept at a good red heat by the successive explosions. The engine follows the usual four stroke cycle. During the admission stroke air alone is admitted to the cylinder, while oil is injected into the combustion chamber and is vaporized there. During the return stroke the air is compressed into the vaporizer, mixes with the oil vapor and forms an explosive mixture which is ignited by the hot walls of the combustion chamber. The proportions of the combustion chamber are designed so that the explosion does not occur till near the end of the compression stroke. The fuel supply is regulated by the governor, which controls a by-pass permitting part of the discharge from the pump to return to the suction side. Before starting the engine the combustion chamber must be raised to a bright red heat by an external heater; but after starting, it is maintained in that condition by the explosions. The engine is of great simplicity since it dispenses with both igniter and mixing valve. The com-

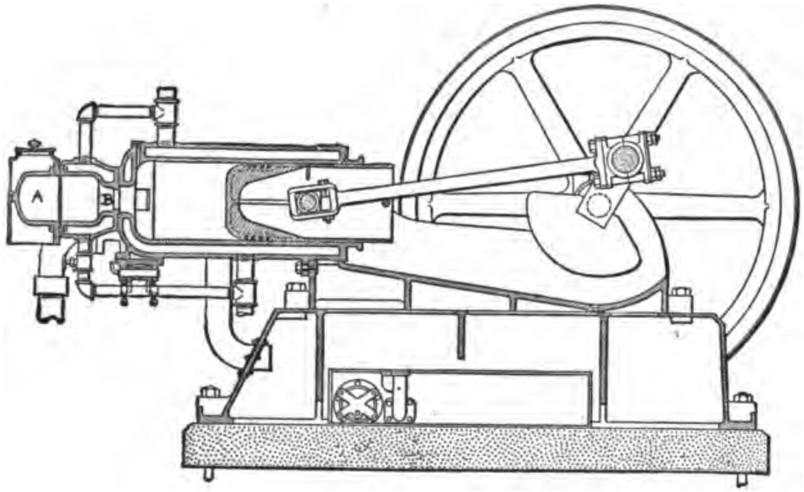


Fig. 53. Hornsby-Akroyd Oil Engine.

bustion chamber becomes coated with a deposit of carbon resulting from the cracking of the oil at the high temperature, but it is easily removed for cleaning.

The Diesel Cycle. All the engines discussed so far have operated on the Otto cycle or some modification of that cycle. There is coming into use for crude oil or fuel oil engines another cycle of operations, known as the Diesel cycle, which merits attention because of its high efficiency. The cycle will operate equally well with gas or gasoline, but is naturally used with the cheaper fuels. The Diesel cycle resembles the Otto cycle in requiring four strokes for its completion. The first out stroke draws into the cylinder a charge of pure air alone, without any admixture of the fuel. On the return stroke the air is compressed; and since the clearance in this engine is only about seven per cent of the cylinder volume, the pressure at the end of compression rises to about 500 lb. per sq. in., and the temperature of the air to about 1,000° F. As the high pressure is reached gradually, it does not cause a shock to the engine, such as an explosion to the same pressure would give. At the beginning of the second out-stroke the oil admission valve opens and a charge of oil is blown into the cylinder in the form of a fine spray by a small quantity of air which has been compressed by a special compressor to about 550 lb. The moment the entering oil meets the highly heated air in the clearance space, it ignites and burns. The combustion goes on so long as the fuel is being blown in, usually for about one-tenth of the forward stroke; and since there is no large quantity burning at any instant, there is nothing in the nature of an explosion. Usually the heat generated by the combustion is not sufficient to prevent the pressure in the cylinder falling while the admission is taking place, so that the admission line on the indicator card falls below the constant pressure line as seen in the indicator card, Fig. 54. The method of burning is really essentially similar to that of an ordinary gas burner, and not to that of an explosive mixture and consequently the oil will burn with any

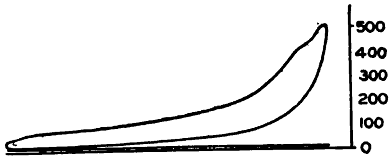


Fig. 54. Indicator Card—Diesel Engine.

excess of air present. After the admission valve has closed, the charge expands and then is exhausted on the return stroke. The indicator card, Fig. 54, shows the cycle of operations.

The general structure of the engine and a detail of the valves are shown in Figs. 55 and 56. The movement of the fuel admission valve is very slight, giving a narrow annular opening for the entry of the oil. Surrounding the valve spindle is a series of brass washers perforated parallel to the spindle by numerous small holes. The oil is pumped into the space around the valve spindle near its middle, and by capillary action finds its way between the washers and into the perforations. The air for fuel injection is

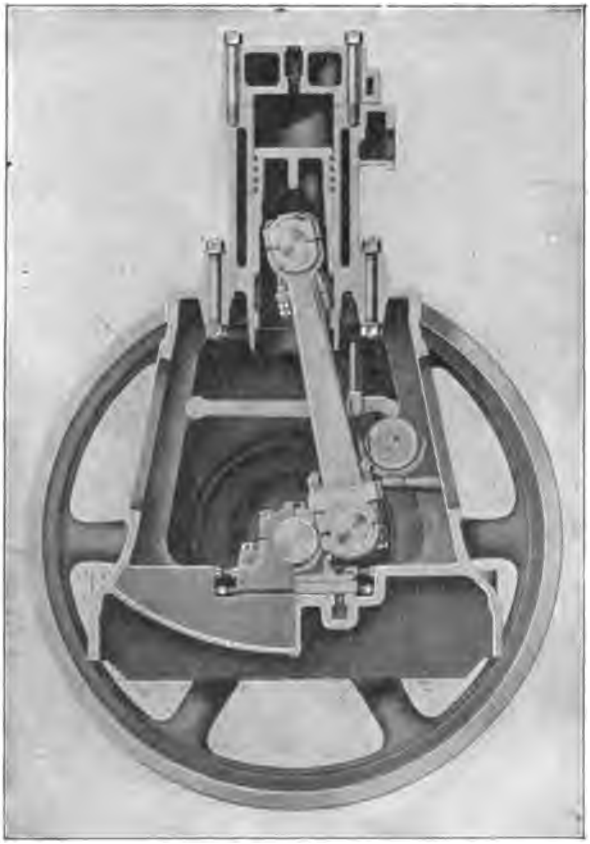


Fig. 55. Sectional View—Diesel Engine.

admitted through another pipe into the same space, but behind the oil, and because of its high pressure blows the oil into the cylinder when the valve opens. The amount of oil admitted is regulated by the governor which controls the time of opening of a by-pass connecting the discharge and suction sides of the oil pump. At light loads the oil is pumped to the fuel valve for part only of the admission period, and air alone will enter past the valve for the rest of the period. The method of slow combustion in a large excess of highly heated air ensures very complete combustion even with the heaviest oils, so that there is no chance for the accumulation of a carbon deposit in the cylinder. The engine is started by compressed air from an auxiliary reservoir, a special starting valve being used for the purpose. Diesel engines have, under test, converted more than 35 per cent of the heat of combustion of the oil into work done in the cylinder.

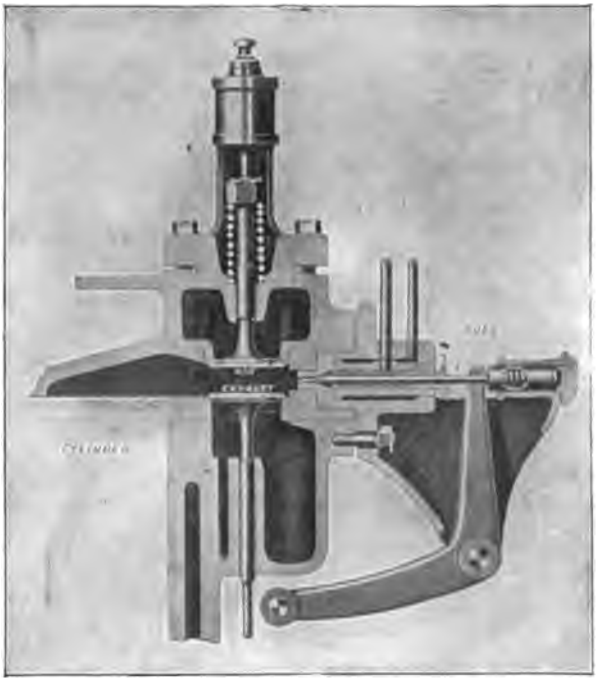


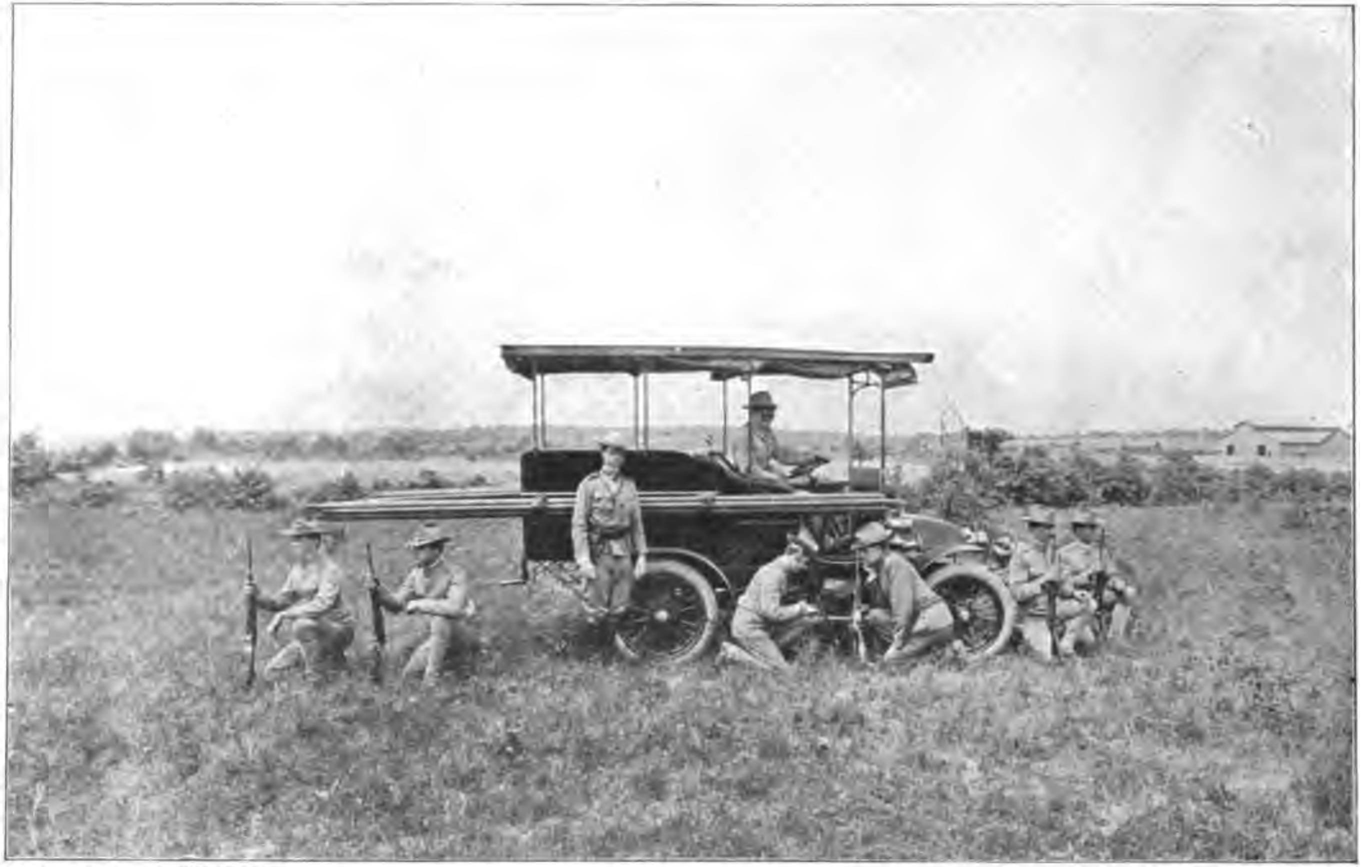
Fig. 56. Valves of Diesel Engine.

The Care of the Oil Engine. The same general precautions are necessary in running an oil engine as in running a gas engine, and the same troubles are liable to occur. The starting by hand of a gasoline engine of small size has been described already. If the engine fails to start, it will probably be because either too much or too little gasoline was admitted. The amount admitted for starting must be varied with the temperature of the cylinder. In cold weather about twice the normal amount must be used, while on the other hand, if the engine has been running and has been shut down for a short time only, a considerable diminished charge is necessary.

Great care must be taken by the use of suitable strainers that no solid foreign matter gets into the oil supply pipe, otherwise there is great liability to the obstruction of the flow. Owing to its more rapid explosion and to the greater richness of the explosive charge, a gasoline engine will develop more power than a gas engine of the same size, even when the latter uses natural gas.

Oil Consumption. The consumption of gasoline in an engine of small size averages about one-tenth of a gallon per brake horse power per hour. In the Diesel motor the average consumption of crude oil per brake horse power per hour is less than one-tenth of a gallon.

The field for the use of the oil engine is very extended. It is the most compact of the heat engines, requiring nothing equivalent to boiler or gas generator, and consequently is inherently the most suitable for purposes of transportation. Its extensive adoption for driving automobiles and motor boats is being followed by its application to locomotives and to large vessels. The absence of boiler and of heat generator losses makes it both potentially and actually the most efficient of all heat engines. The relative cost of power developed by oil, gas and steam engines depends on the cost of the oil and of coal, and this varies with the locality and the kind of oil or coal. In refining petroleum not more than ten per cent of the oil can be collected as gasoline, so that this oil, which is the most easy to use, is not available in as large quantity, and consequently has a considerable higher cost than the heavier oils. Kerosene forms twenty-five to fifty per cent of the crude oil, and is consequently cheaper. Fuel oil and crude oil are the cheapest, but are also the most difficult to burn satisfactorily.



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USE OF THE AUTOMOBILE IN WAR.—AUTO-TELEGRAPH CAR OF THE SIGNAL CORPS, U. S. ARMY.

A Scene during the Manœuvers of 1904 on the Historic Battlefield of Bull Run.

AUTOMOBILES

As a device for saving time and distance, the motor vehicle bids fair to eclipse all others and to prove itself one of the greatest inventions of an inventive age. Its motor will, in time, be built cheaper than a horse can be grown, its transmission gear will cost less than a harness, while its body need cost little, if any more than similar parts of horse vehicles. Rapid as has been the growth, and astonishing as are the results shown to-day by this class of vehicles, it is evident that this is but the beginning and that in the very near future, a development and growth far beyond present conception is sure to come.

The motor vehicle is not a new invention. It is the father of the traction engine and of the locomotive. It is one of the devices earliest sought for but latest to be practically and popularly worked out; and few problems of greater severity have been presented to engineers. Its need has been felt everywhere, for we spend our lives exchanging what we have for what we desire and this requires transportation. At both ends and often between ends of the route over which the exchange is made animal power is used and here the auto is needed and will be used with great saving. The director of the United States Road Inquiry Bureau says the cost of moving tonnage 1250 miles by steamships, 250 miles by steam cars, or 25 miles by electric cars is no greater than the cost of moving tonnage 5 miles by animal power on the common roads—a proportion of 1 to 5, 1 to 50 and 1 to 250 in favor of mechanical transportation against the horse; and yet with these figures before them, capitalists build larger steamships and better railways in an attempt to save an additional slight percentage on these already cheap methods, while the horse has continued to draw the same old wagon at a snail's pace over abominable roads, simply because heretofore the motor vehicle has not come into use.

On the other hand while this has been the general condition, there have always been attempts to secure better results. Pioneers have exerted themselves to build mechanical motors for use on the common roads in the face of the great chances of failure and the derision of the world. To them we owe the progress that has been made.

HISTORY

Nearly three centuries ago a German at Nuremberg proposed to drive vehicles "2000 paces an hour by means of springs," and similar carriages were proposed by others. In 1759 Dr. Robinson called the attention of Watt to the possibilities of steam vehicles. In 1763 to 1769 Cugnot, a Frenchman, designed and built with the assistance of the French War Department, a steam-propelled gun-carriage and in 1797 a four-passenger tricycle capable of four miles per hour. In England a practical result was shown in 1781 by Murdock and in America by Oliver Evans in 1804. These were mostly steam vehicles, although gunpowder engines much resembling gas engines were among the earliest proposed. Compressed air was also used, notably by Mann in 1822 and others.

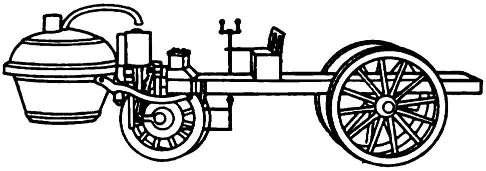


Fig. 1. Cugnot's Steam Carriage, 1769.

The first half of the 19th century was marked by many attempts at motor road-locomotion and many vehicles, particularly omnibuses for public hire, were made and operated between 1820 and 1844 by Hancock, Gurney, Church, Fisher, James, Squire, Russell (constructor of the Great Eastern Steamship) and others. These vehicles were operated with success on regular schedules over regular routes, were much liked by travelers and were crowded with passengers, and they bade fair to inaugurate the horseless age and bring in an era of cheap transportation.

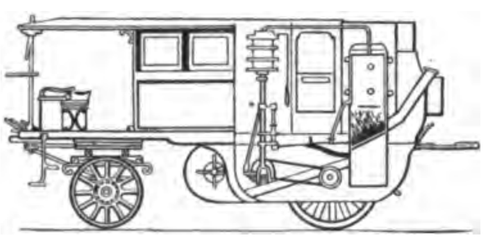


Fig. 2. Hancock's Steam Carriage, 1836.

Public opinion, however, was not with these vehicles. Horse users and stage drivers were very bitter against them. The Road

Trustees imposed unjust and discriminating tolls and the ill feeling and prejudice finally resulted in restrictive laws prohibiting a speed faster than three or four miles per hour and compelling a man to precede the vehicle with a red flag. The result was that the industry died and did not again exist in England until the passage of the "Light Locomotives Act" in 1896, a loss of more than 50 years and of millions of dollars that would otherwise have gone to the English nation. In the meantime the locomotive was developed to run on special rights of way and the traction engine plodded at a snail's pace whenever it used the highways.

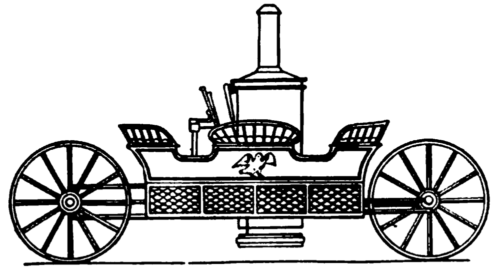


Fig. 3. Fisher's Steam Carriage, 1840.

Occasional Experiments. Occasional inventors made experiments from time to time in France, Germany and America, but for one reason or another none of these found favor In 1860 to '62 Lenoir, a Frenchman, designed a gas engine of the four stroke cycle type and applied it to a motor vehicle. Ten years later the elder Bollee built one or more steam vehicles which received some use on French roads. About 1876 Fawcett, at Pittsburg, built an omnibus using a Brayton internally fired engine burning liquid fuel. Ten years later Copeland in America fitted small, light steam motors to bicycles and tricycles with some degree of success, while Daimler and Benz in Germany about the same time applied gas engines of the four cycle type successfully to motor vehicles.

The next ten years marks the beginning of the present motor vehicle industry. In Germany, Daimler developed the small high speed motor which is admittedly the predecessor of present day practice. Benz, his countryman, confined himself more to the application of engines resembling stationary engines, and while very successful, so far as quantity of vehicles made and service rendered is considered, did not influence the industry as did Daimler whose inventions were taken up in France about 1892 or '93. In America, occasionally experimenting since 1886, the Duryea Bros. began continuous work on gasolene vehicles in 1891, which work unlike many experiments, has been carried forth continually since. In 1893 Sturgess, of Chicago, exhibited an electric vehicle at the Columbian Exposition.

In 1894 and 1895 very successful road contests were held in France and attracted the attention of the civilized world. These were followed by several automobile events in America, the first of which was the Times-Herald contest at Chicago.

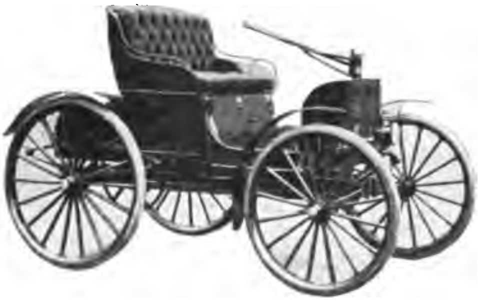


Fig. 4. Five Horse-Power Runabout, 1896 Model.

Pioneers. It is difficult in a historical account, to set a proper value on the various experiments and attempts made in different parts of the world, for no one can say what bearing or influence any particular experiment may have had on the work of later builders. It is eminently proper, however, to give credit to work that has continued with little or no interruption into the present period; to work that showed marked pre-eminence either by the results accomplished or by the means and mechanism used, and to work that has in any way stamped itself upon present practice to a noticeable extent. Judged by these standards the pioneers in the electric vehicle field were Sturgess, 1893, Morris & Salom, 1894 and '95, Woods, 1895 and Riker, 1896. In steam vehicles the work of Copeland was followed about 1896 and '97 by the successful steam carriage of Whitney, which was the direct predecessor of the product of the Stanley Bros., first introduced to the public at Charles River Park, Boston, Mass., in the fall of 1898. In gasolene vehicles, the

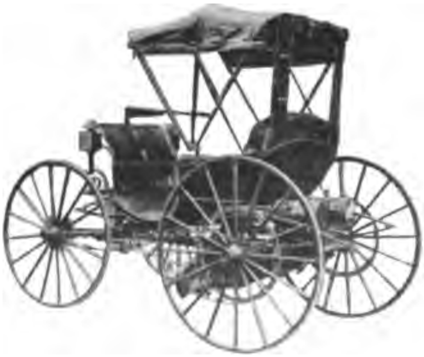
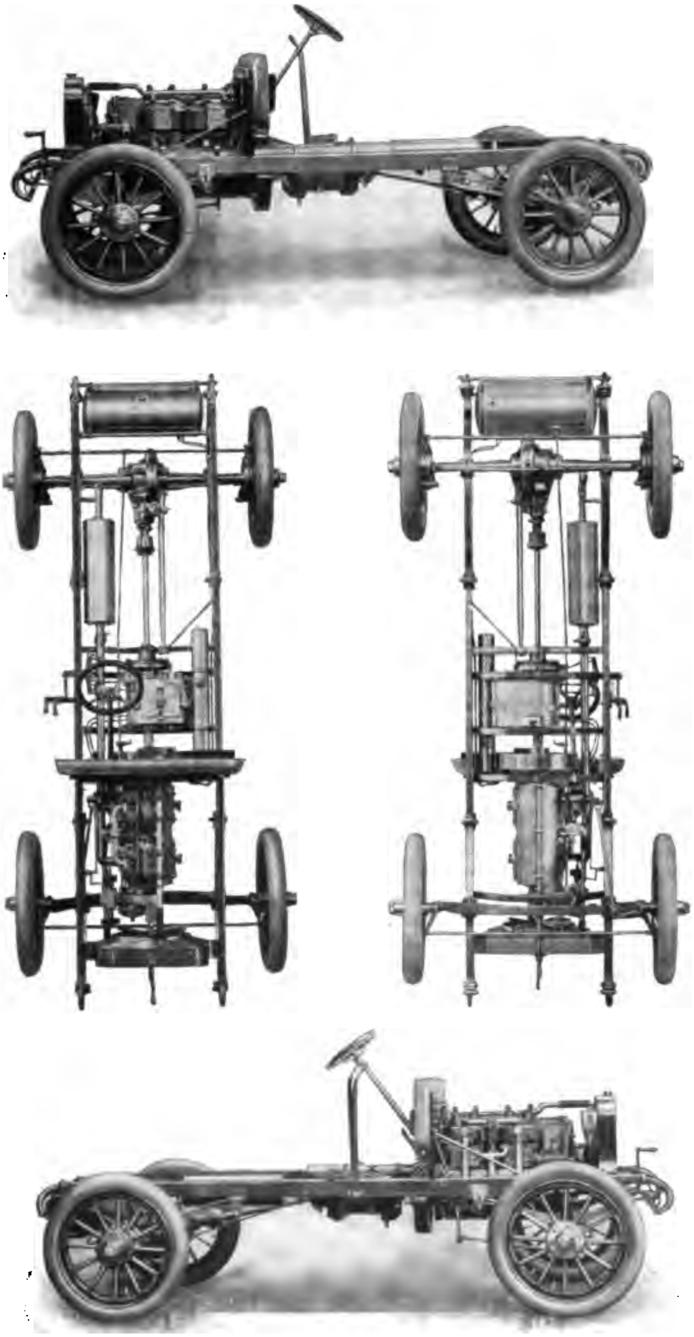


Fig. 5. Two and One-Half Horse-Power Phaeton, 1892 Model.



GROUP OF MODEL K CHASSIS
The Winton Motor Carriage Co.

first Duryea finished in 1892, and the second one finished in 1893, both of the single cylinder variety, were followed in 1894 by the double cylinder carriage which won the Chicago Times-Herald contest. The first single cylinder Haynes vehicle was finished in the summer of 1894, followed late in 1895 by the second Haynes, a two cylinder vehicle, the first of the opposed cylinder type. In 1896 the first Winton made its appearance, while in this same year more than a dozen Duryea vehicles were completed and the new industry was fairly started on its way.

Little Interest. Progress was at first slow both in America and England, although more rapid in Germany and France, due to the favorable roads, liberal laws and greater interest among experimenters and capitalists. In America, the downfall of the bicycle business destroyed much of the financial confidence necessary to the development of the new industry and interest lagged until the steam vehicle shown by the Stanleys in 1898, and offered to the public by many makers at a low price, began to be put on the market in a large way and extensively advertised. It met with an enthusiastic reception, was not protected by patents and was therefore largely copied by other makers, with the result that it seemed to have the field to itself. The steam vehicle, as then constructed, however, fell from popularity, even more rapidly than it attained it. The great complexity, the delicacy of the many parts, the small wheels, the inadequate tires, the short wheel base, together with many other features of similar character, all contributed to the downfall of this promising, popular carriage.

In the meantime, the electric vehicle was being exploited by large capitalists in the large cities for public service, and cab companies, overcapitalized, sprang up in many places, doomed to disappointment because of the lack of experience and the fact that their vehicles had not been proved by years of service to be what was needed for their work. This adverse experience did much toward holding back the adoption of the electric vehicle by many to whom it would have been of great value, and hurt the business generally.

Steady Growth. Across the ocean Serpollet, beginning about 1886, had been slowly developing a promising steam vehicle while one or more experimenters were developing the electric. The gasolene vehicle, pushed by many, made most rapid progress. In America also, it made progress conservatively but steadily. Fathered by mechanics, rather than by capitalists and promoters, it was steadily improved, its defects and limitations were studied, it was sold at a price consistent with good quality, and although slow in coming to its recognition, the certainty of that recognition was made more sure by the very length of the period devoted to its development.

This slow growth gave opportunity for experimentation and brought into existence most of the valuable features of present day autos as well as some features that will undoubtedly be used in future years, although not recognized at their true value now. Thus the first Duryea vehicles, finished in 1892 and 1893, had front axles fitted with wheel pivots or steering heads as close to the wheels as possible, and these pivots were inclined, so as to strike the ground at the bottom at the point of contact of the wheel, which arrangement secures a steering that is practically irreversible, that steers very easily and permits running over obstructions with no shock on the steering parts or tendency to deviate from a straight line—facts which are not yet fully known by constructors and therefore not made use of to a large degree. They employed a three point rear frame with motor and transmission mounted closely together upon it, double side-chain drive with balance gear in the counter shaft, electric ignition, spray carburettor, motor lengthwise the body and many other devices that have since become standard practice.

This period of the history of the gasolene vehicle was not influenced by foreign practice and was more truly American and better suited to the American roads and conditions than many present-day constructions, although at that time the full importance of ample power was not recognized, mechanics were untrained, and many vehicles were incapable and unreliable.

Steam Decadence. About the time of the decadence of the steam vehicle fad, 1901, two vehicles of particular importance began to attract attention,—the Olds and the Knox. The Olds is interesting because of the distinctive shape of the body which resembled a toboggan at its forward end, the shape of the springs, which were fastened at one end to the body and at the other to the axles, and the generally light and simple appearance. This vehicle was put out in large numbers at a moderate price, was quite successfully imitated by many other concerns, and was for a time the representative American type, and recognized as such in many parts of the world. The Knox equally deserves mention because of its system of air cooling, which was really the only successful form for a considerable period. Many attempts had been made at air cooling, but most of them had been failures for one reason or another; but Knox, by his firm belief in the efficiency of threaded pins screwed into the walls of the cylinder, including the head and valve chambers, demonstrated the practicability of this system, and although standing alone, after others had abandoned air cooling, for all except the smallest sizes, has been followed by a great variety of very efficient air cooling methods.

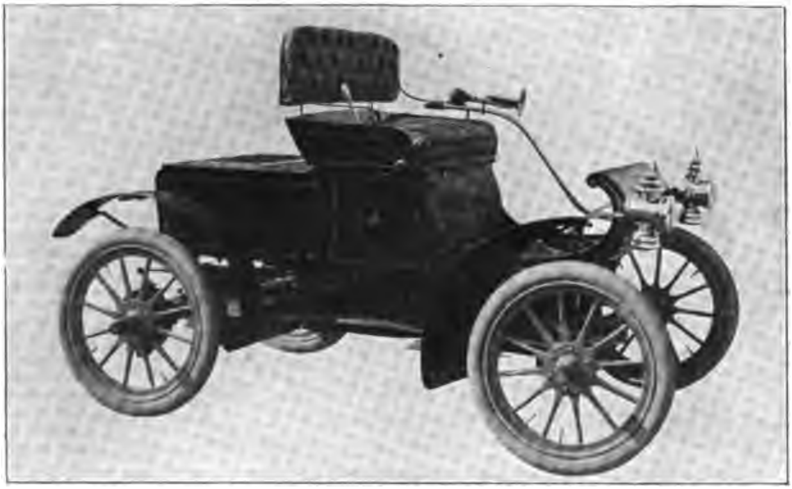


Fig. 6. Standard Oldsmobile Runabout.

Foreign Influence. Abroad, the gasolene vehicle was turned out in large numbers, and was seen, tried, admired, and purchased by the vast number of American tourists, who, too busy at home to even look at an auto, became willing converts abroad and spent their vacations enjoying the good roads of Europe and the new method of locomotion at the same time. The earliest vehicles of Daimler had been fitted with a motor under the seat, but in order to secure greater accessibility he soon transferred this to the front of the vehicle, where it was enclosed in a box, and this practice has prevailed abroad to the present day and has been followed very largely in America through the influence of the tourists.

The splendid foreign roads with their hard surfaces and easy grades permitted the use of small wheels, of mechanism close to the ground and required so little traction that no great weight was needed upon the driving wheels; while favorable speed laws and road conditions permitted the use of high powers and the attainment of railroad speeds.

American Conditions. In America, where the majority of the roads are bad, the things demanded of a motor vehicle are considerably different, and they are not properly met by foreign designs so prevalent to-day. Rough roads require large wheels, ample clearance under the body, protection of the mechanism from mud and dust, great weight on the propelling wheels, large wheels that will roll over rough places easily, a simple and light mechanism that will stand the rough service with the minimum of repairs. Many other similar features are essential to meet the road conditions and also the needs of a thoroughly practical people, rather than those designed simply to serve as a sport of a leisure class. It seems evident, therefore, that many of the features first developed in America, to meet American conditions, and more or less largely abandoned in favor of foreign design, will eventually become standard American practice, because best suited to American needs. Fluctuations are, of course, apparent in the development of any new industry, for, in their inexperience, the buying public is apt to grasp at new designs as the solution of its difficulties, without really knowing whether the new is better or as good as the old, but as a wider variety of styles is seen in use, these fluctuations will become less pronounced until finally purchasers will have a large variety from which to select and particular needs rather than present fad will more largely influence the selection.

Present Types. Present-day autos can be divided into a wide number of classes in addition to the three general classes, electric, steam and gasolene, already considered. In electric vehicles, there is but little variation except in the shapes of the body, although some vehicles are equipped with two motors, others with but one, and batteries vary somewhat in arrangement, kind, and size, while controllers and fittings exhibit the designers' preferences.

The electric vehicle is of limited range and well adapted to city use for elderly people or ladies. Like the steamer, it seldom needs attention on the road and generally gets home if the batteries are not exhausted. The batteries, like the steam boiler, are the objectionable feature, for they are quite complicated, heavy, subject to chemical change; also to physical change, such as buckling, loosening of the active matter from the plates and leakage, spilling or evaporation of the electrolyte. The density of the electrolyte needs watching to secure best results, and the batteries should always be kept charged.

Steam Vehicles. These are considered well-known because they employ steam engines and boilers and do not ordinarily use a speed changing device. The White steamer uses a tubular generator in which the water enters the top and is converted into superheated steam by contact with the hot metal. No water is carried in the boiler, so little time is required to get up steam, and an increased supply of water is met by an increased fuel supply, resulting in increased quantity of steam. With the steam vehicle, pressure is required to make the fuel mix with air, and the burner requires more or less attention. The piping, pumps and stuffing boxes must be known to be in good order, and loss of power is usually attributed to a leak or to improper fuel and water supply.

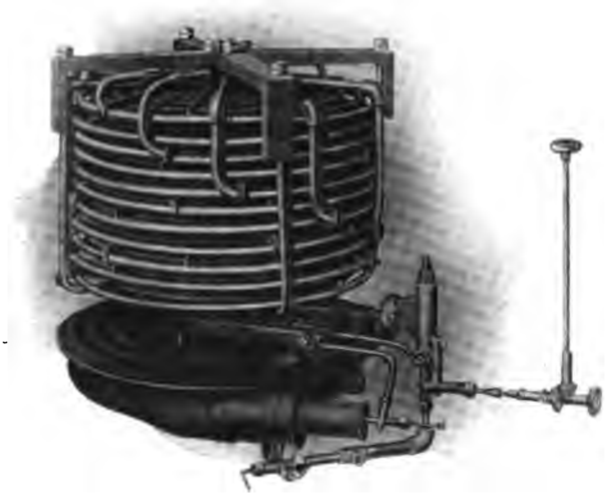


Fig. 7. White Tubular Generator.

In the Stanley steamer, the motor is geared direct to the rear axle, instead of being connected by chain as in most other forms. The light weight of the Stanley steamer, and also the Baker electric vehicle contribute much to the high efficiency shown by these light carriages.

Steam vehicles differ principally in the type of boiler, there being two general kinds, the fire tube, of which the Stanley is best known, and the flash or generator, of which the White is the principal exponent. Burners, engines and their arrangement vary also.

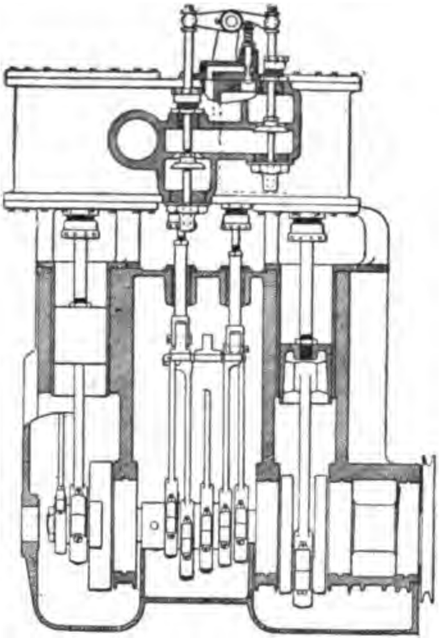


Fig. 8. Diagram of White Steam Engine.

Variations. Since, however, the majority of present day autos are gasolene vehicles, it will suffice to describe in them, most of the details that enter the auto of to-day. Besides the variations in the body, such as single or double seat, folding seat or detachable, open, with top or enclosed, side or rear entrance and many similar variations, there are two kinds of motors, two-stroke cycle and four-stroke cycle; two varieties of cooling, air and water; three locations of the mechanism, front, midway and rear; several forms of transmission, such as belt, friction, chain, planetary gear, sliding gear, individual clutch, and many variations including combinations of hydraulic and electric systems. There are two largely-used methods of ignition, with several accepted sources of electric current, viz., the jump and the contact spark; with primary batteries, storage batteries, magnetos and dynamos for supplying the electricity. Since, however, there are several hundred parts required to make up a motor vehicle, it seems best to describe these parts under various headings rather than attempt a general description which cannot be other than confusing.

The motor vehicle is commonly considered as a combination of a motor and vehicle with such other parts as are needed to make the combination operative, and in this connection the motor is described first. Since, however, vehicle motors are but modifications—usually light and of high speed—of motors long used for stationary work, it will not be necessary to include here so complete a description as would otherwise be the case, since this information can be obtained in text books treating directly of the motor.

THE MOTOR

The theory of the gasolene motor is that a mixture of air and gasolene vapor is drawn into the cylinder of an engine and ignited, after which the pressure, due to the expansion, is caused to perform work in propelling the vehicle. The essential parts are the *cylinder*, *piston*, *crank shaft*, *fly wheel*, *inlet* and *exhaust* devices, *ignition* arrangement, *vaporizer*, and means of *control*, together with important incidentals, such as lubrication and means for cooling..

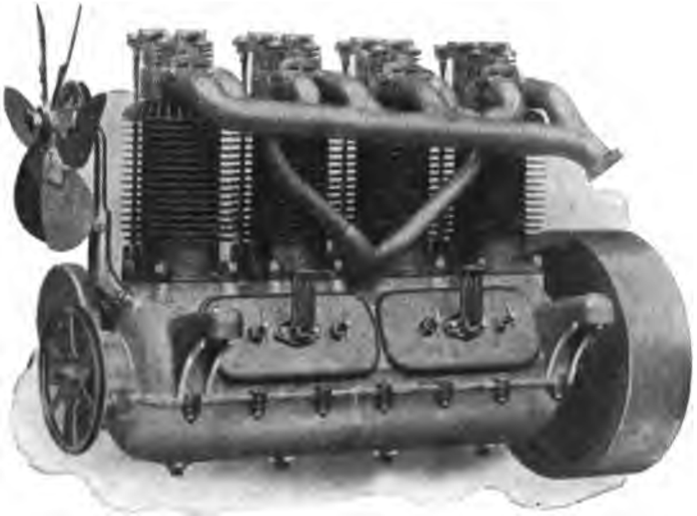


Fig.9. Four-Cylinder Gasolene Engine.

Cylinder. The cylinder of the engine for auto use is usually from three to six inches bore, with stroke sometimes longer, sometimes shorter, but quite generally the same as the bore. Cast iron is the usual material from which the cylinders are made, and provision for cooling, such as a water jacket, is usually cast integral with the cylinder, although quite frequently affixed in the form of a sheet metal jacket or fins after the cylinder is machined. These cylinders may be attached to the crank case or formed with part or all of the crank case in one piece. Each method of construction has its followers and each has its advantages, according to the design of motor, crank shaft and similar parts. In motors of the type first used on DeDion tricycles, the flywheels were disks enclosed in the crank case and forming the crank sides, and since they practically filled the crank case, it was necessary that this be made in separable halves. The separation was in the plane of the crank rotation, which permitted each half of the case with its long, hardened and lapped but nonadjustable bearing, to be removed by sliding off opposite ends of the crank shaft. The cylinder was held to this case after the halves had been brought together, by screws or bolts. In many instances the head of the cylinder was held against the cylinder end by the same bolts, so that the cylinder was actually clamped between the head and the case. This design employed a cylinder open at each end, making a quite simple casting and facilitating machining.

Other cylinders are built with a simple head screwed in position, and with the ports on the sides of the cylinder instead of forming part of the head. Air-cooled cylinders are most frequently provided with circular flanges spaced one to three times their thickness apart, and rising above the cylinder wall from two to ten times their own thickness. In some cases these flanges are of sheet metal of great conductivity, as copper, forced tightly upon the smooth wall of the cylinder, or they are of smaller pieces attached by calking, clamping or other effective form of contact in or to the cylinder wall. It is essential for good results, that the cylinder should be true, particularly when hot, for if it is not truly round, and practically parallel throughout its length, the piston rings will not fit, and will not retain the gases which, leaking past the piston, leave their heat in the cylinder walls, blow away and burn up the lubricating oil, and cause excessive heating, pounding, loss of power, premature ignition and even cutting of the metal surfaces, destroying both piston and cylinder.

Valve Ports. The most common arrangement of the ports employs a pocket or passage at one side of the cylinder head in which the valves and frequently the sparking parts are placed. The exhaust valve is the nearest the crank shaft, with its stem extending toward the crank shaft where it is conveniently operated upon by the cam on the half time shaft which lifts the valve every second revolution, as is required in a four cycle engine. The inlet valve is placed with its stem in the same axial line but projecting in the opposite direction, and is held closed by a spring and opens by the suction of the piston. By this arrangement the cool incoming charge strikes the exhaust valve and sparker parts and much reduces the temperature. Burnt gases are carried out of the pocket, leaving a fresh combustible mixture therein which contributes to certain ignition.

Recent designs have employed double cam shafts on opposite sides of the motor with valve pockets likewise on opposite sides, the inlet valve being mechanically opened, and arranged the same as the exhaust valve. These double pockets increase the wall of the compression space and therefore the loss of heat, and lessen the economy.

To avoid this increased wall surface of the compression space, many constructors now place the valves in the head of the cylinder with their stems projecting away from the crank shaft, and operate the valve by rocker arms, or place the cam shaft beyond the cylinder head and drive it by chain and sprockets instead of gears.

Whatever the form of cylinder and fittings, it is essential that there be good compression, or, in other words, that the contents of the cylinder be not allowed to escape. To test the compression, turn the engine by hand until the piston comes against the contained gases as against a strong spring, and judge by the length of time that this resistance continues as to the rapidity of the escape. A tight cylinder properly lubricated ought to resist a pull on the starting crank for a minute or more and should require considerable effort to force the engine past the compression. The operator should distinguish between high compression and good compression. If the clearance at the head of the cylinder on the compression dead center is small, the engine is known as "high compression" and if turned quickly, the resistance will be high, even though the valves or piston rings may be leaking and the compression therefore not good.

Faulty Compression. If the compression is faulty the escaping gas can usually be heard, announcing its escape by hissing. The point of escape must then be found and will usually be at the exhaust valve, for the inlet valve, being kept cool by the incoming charge, seldom needs attention. If the passages can be opened, a candle flame will, by its flickering, indicate the leak, to remedy which the valve must be removed and ground. Grinding a valve consists in oscillating it upon its seat until the high spots are worn down, so that the valve bears equally and fully all around, thus making a tight joint. Flour emery mixed with oil is usually used, but a tighter and smoother job may be secured by finishing with powdered glass or sharp sand like the powder from the water-trough of a common grindstone.

If the leak is around the piston rings, new rings or newly fitted pistons may be needed. To avoid damage to the piston or cylinder, the operator should stop immediately if the engine begins to pound, smoke, or lose power, and he should determine the cause of the trouble before proceeding. Lack of water, a broken belt on the cooling fan, or lack of oil will usually be found causing the trouble.

Piston. The piston is the moving part which fits into the cylinder and against which the explosive pressure is exerted by the burning gases. Pistons are usually from one to two times their own diameter in length and are provided with two to four rings at the head and and occasionally with one ring at their open end. They are unlike steam engine pistons in that the pressure is taken on the head end only and that they serve as cross heads, having the connecting rods attached to wrist pins fitted generally about midway the length of the piston. This wrist pin ordinarily passes through the piston walls, lugs or enlargements being provided interiorly therefor. The wrist pin is usually fixed in the piston and the end of the connecting rod has a bearing thereon, although in some cases the pin is fixed in the end of a rod and takes its bearing in the piston, by which means a larger bearing surface is secured, and removable bushings are fitted in from the out-

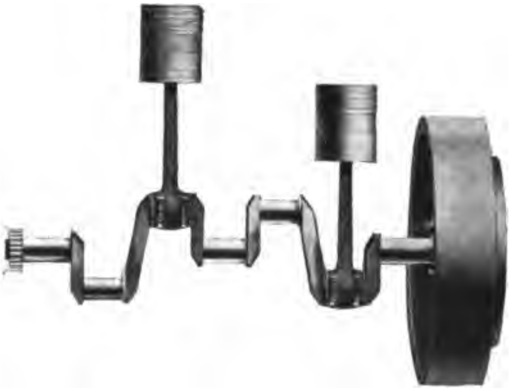


Fig. 10. Pistons and their Connections with Crank Shaft.

side of the piston, as in Rambler autos. The head of the piston is quite commonly flat, but is frequently concave as in the Duryea, or convex as in the Autocar, and these forms are stronger and lighter than the flat head. The interior of the head is sometimes provided with radiating webs or pins as in the Frayer-Miller. The piston rings are usually of cast iron machined to a diameter larger than the diameter of the piston and then cut so as to be compressed to the cylinder diameter, which leaves them with a tendency to open and causes them to fit closely to the cylinder wall. They should be fitted carefully to their grooves in the piston, and it is particularly important that their sides be carefully fitted to the sides of the groove, so as to make a gas tight joint and prevent the escape of the gas under the ring. Two rings are often fitted in a single groove with their joints in different positions, and a third ring is sometimes placed underneath, which also serves to close the joint. Various joints are used, but a plain cut of 45 degrees or two perpendicular cuts from opposite sides, each cut being on opposite sides of a dividing line, are sometimes used, making a lap joint that is regarded as superior to the diagonal joint. Care should be taken in removing and replacing piston rings not to spring them harshly, for they will seldom return to their original shape if much abused, and if they do not fit the cylinder they will not serve their purpose properly.

Connecting Rods. The connecting rod attaches the piston to the crank shaft, and since auto engines are desired to be compact, these rods are 1½ to 3 times the piston throw. They are generally of I-beam section, so as to resist the alternating stresses to which they are exposed, but are frequently of U-section, particularly in horizontal engines, so that they may catch oil and direct it into the bearings and thus assist in efficient lubrication. Connecting rods are usually made of forged steel, but steel castings and bronze castings are sometimes used. The wrist end is very frequently solid and fitted with a bushing for the wrist pin, but in many forms this end is provided with a lug at one side, split and drawn together for adjustment by a screw. Occasionally a removable cap is fitted. At the crank end the removable cap is the more common construction. Sometimes this cap is hinged at one side and

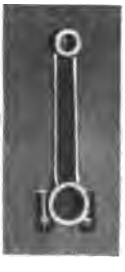


Fig. 11. Connecting Rod.

adjusted by a single screw at the other. Bushings of Babbitt metal are very commonly fitted at the crank end.

Crank Shaft. The crank shaft is usually of a high grade steel and is frequently hardened and ground. Bearings are provided at short distances apart, frequently between all cylinders, and seldom if ever farther apart than is required to bring two cylinders as close together as possible. This large amount of bearing surface contributes to long life, and also supports the crank and thus prevents danger of damaging the bearings by strains or damaging the shaft. A wide variety in shafts is found, depending upon the type of engine, the number of cylinders, the class of bearings, and the objects of the designer. Where ball bearings of the nonadjustable type are used, the crank shafts have been built up in short pieces, so as to permit putting the ball bearings into position, but this method is not very common. Shafts are frequently made hollow, both in the shaft proper and in the crank pin, for by so doing nearly one fourth the weight can be saved, with little decrease in strength.

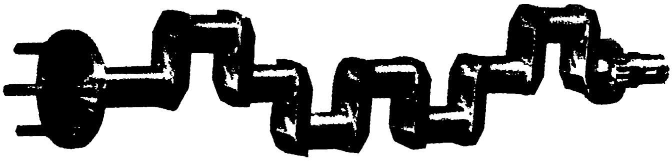


Fig. 12. Crank Shaft.

The common method of attaching the fly-wheel to auto crank shafts is by means of a flange integral with the crank instead of keyed on, as in most other engine practice. The web of the fly-wheel is bolted to this flange by an ample number of bolts to hold it securely and yet permit easy removal. The saving in space lengthwise of the crank shaft makes this method of particular value in a vehicle like the Duryea, where the width of the body limits the length of the shaft available for the engine and transmission gear, particularly in connection with multiple-cylinder engines. The crank shaft is usually provided at one end with ratchets for starting purposes, with a gear for driving the cam shaft and any other fittings such as pump or magneto, while at the other end the fly-wheel and the connections for the transmission gear are placed.

In some cases the fly-wheel is on the end of the crank shaft opposite the transmission gear, but this is not considered the best practice, because, in suddenly setting a clutch, the inertia of the fly-wheel is transmitted through the shaft to the transmission gear, causing a more or less severe strain on the shaft and requiring a stronger shaft than would otherwise be necessary. In two-cylinder engines it is customary to set the two cranks of the shaft opposite each other, or 180° apart. Other arrangements have been used but have not been found so satisfactory as this. In three-cylinder engines, the cranks are 120° apart and in four-cylinder engines they are 180° apart or the same as if two two-cylinder cranks had been joined end to end with the two outer pistons moving together and the two inner ones together. For six-cylinder engines the setting is the same as if two three-cylinders had been joined—the inner, intermediate and outer pistons respectively moving together. Three bearings for a four-throw shaft and four bearings for a six-throw is quite common practice, as is also five and seven bearings respectively. A few engines have cylinders which revolve around a stationary crank shaft, and in these a single throw shaft is usually used, the Adams - Farwell having five connecting rods attached to the single crank pin. When the engine "knocks" at speed, whether hot or cold, a loose connecting rod or loose fly-wheel should be looked for, lest the shaft be broken by the constantly repeated blows.

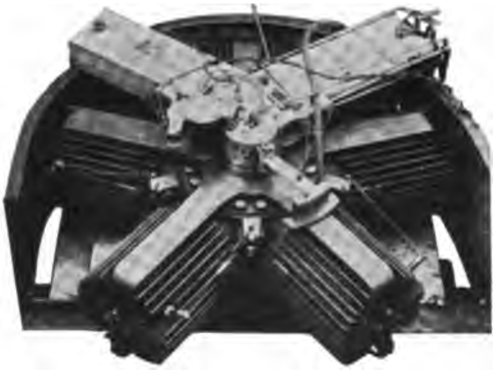


Fig. 13. Gasolene Engine with Revolving Cylinders.

Fly-Wheel. The fly-wheel of a gas engine is a sort of necessary evil. Since in a four-cycle engine there are three idle piston strokes to one working stroke, a fly-wheel is necessary to store up the energy of the one working stroke and carry the engine steadily through the three idle strokes. In a single-cylinder engine this fly-wheel must be of considerable size, weighing when used with a cylinder of 4½ x 4½ inches, 150 to 200 pounds. With two cylinders there are double the number of explosions and consequently only one idle stroke between the working strokes, so the fly-wheel can be reduced in weight nearly one half. With three cylinders the working strokes follow each other with but one sixth of a revolution intermission and a 55-pound fly-wheel, as used on the Duryea, after a long experience with a variety of weights, serves nicely. A three-cylinder engine may be run without any fly-wheel whatever, but this is not considered practical, although a 25-pound fly-wheel, 18 inches in diameter, serves quite well in a 12 H. P. engine, for all except very slow speeds, at which the separation of impulses becomes so pronounced that is is disagreeable.

In order that the weight may be as little as possible, the fly-wheel is made of the largest practicable diameter and the weight is kept as fully in the rim as may be. In many cases the interior surface of the fly-wheel rim is used to form the clutch surface, while the magneto pulley or pump pulley is driven by friction against the outer surface, which in some cases also serves as the driving face for a fan belt. The spokes are screw-propeller shaped in some instances, to throw air for cooling. In others the face of the wheel is a plane and is used for a friction disc, with the edge of another disc bearing against it, and shiftable to vary the speed of the driven disc.

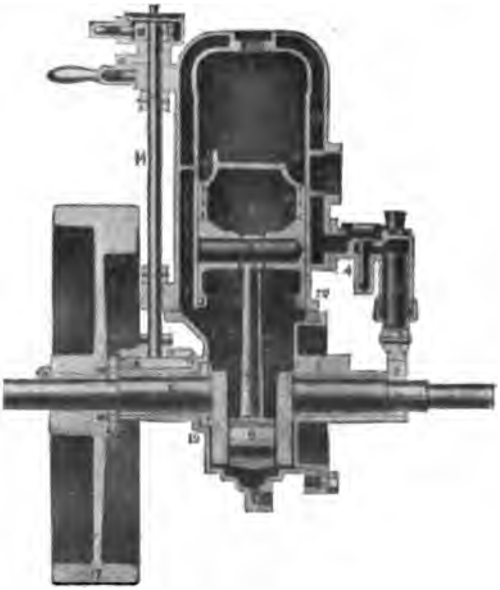


Fig. 14. Section of Gasolene Engine, Showing Enclosed Crank.

Crank Case. In a two-cycle engine the crank shaft is usually enclosed in a tight case arranged to hold pressure to the amount of 5 or 10 pounds under running conditions, although strong enough to hold an explosion which may sometimes occur in the crank case. The cylinder is provided with ports uncovered by the piston at one end of the stroke, which serve to exhaust the burnt charge and admit the new charge from the crank case into the cylinder proper. Most two-cycle engines are further provided with an inlet port uncovered at the opposite end of the stroke to admit a new, charge from the vaporizer into the crank case, where it is compressed by the return, ready to pass into the working end of the cylinder on the opening of the transfer port. Some two-cycle engines have valves, usually of the poppet type, to pass the unburned gases, but these are generally automatic and do not add much complication.

In the four-cycle engine, the cylinders serve the double purpose of containing the working charge during one revolution of the shaft, and the new charge during the next revolution, thus avoiding the use of the crank case as a charge-containing chamber, but requiring two revolutions instead of one per explosion as in the two-cycle engine.

Valve Action. To accomplish this result with a single cylinder, valves are used both for inlet and exhaust, which are operated ordinarily by a half-time shaft fitted with cams arranged to open their respective valves during substantially one stroke of the four strokes forming the cycle. The exhaust valve is opened about 20 to 25 degrees ahead of the crank shaft dead center, and closed at the opposite dead center one stroke later. The inlet valve immediately opens, and it closes at the end of the next stroke one revolution after the exhaust valve opens. Both valves remain closed during the compression and working strokes.

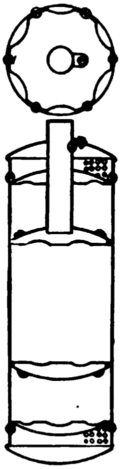


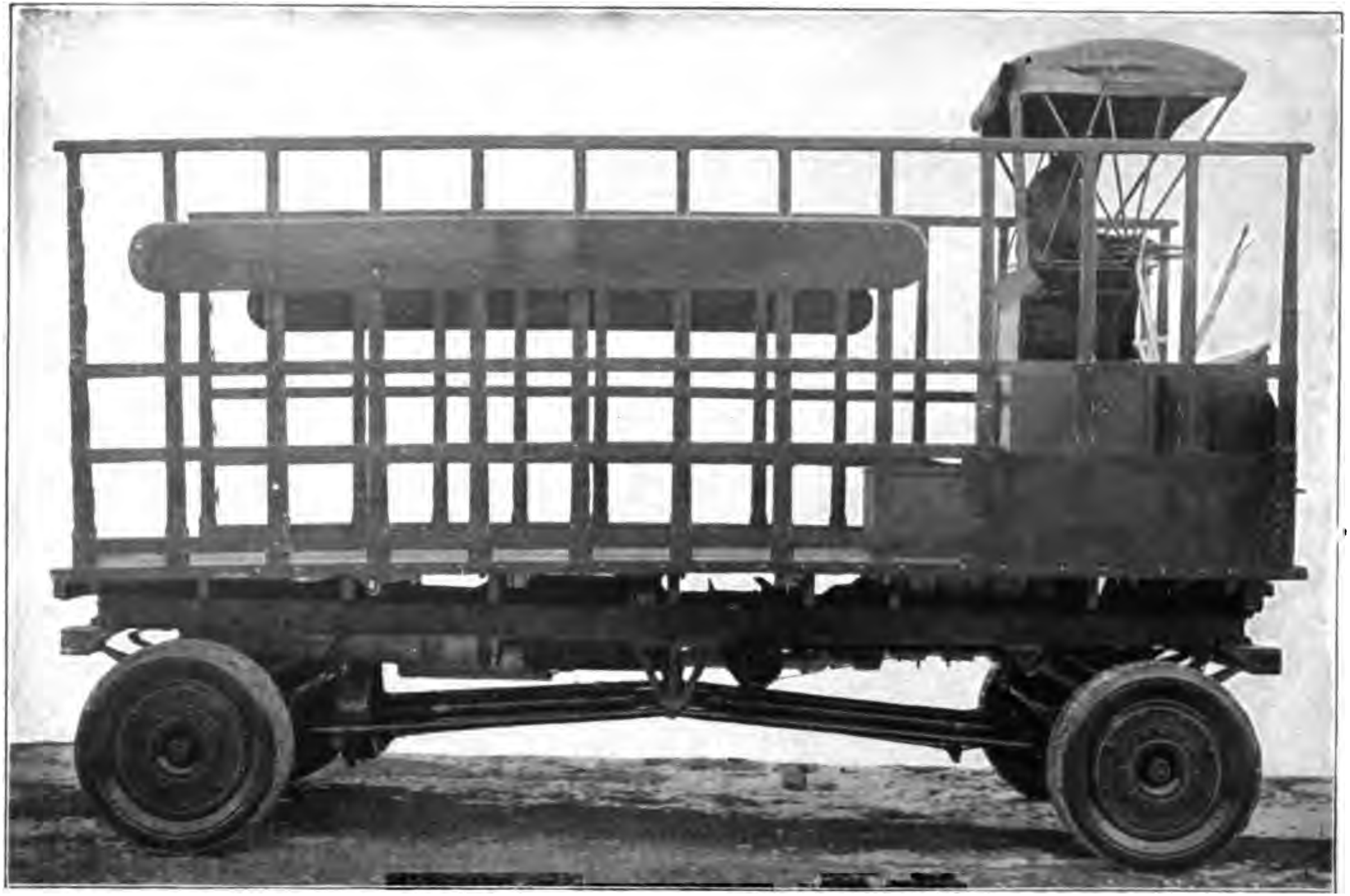
Fig. 15. Diagram of Muffler.

These valves are variously placed according to the ideas of the designer. A common arrangement places them in the head of the engine with stems projecting from the crank shaft, in which position they are usually opened by rocker arms and plungers actuated by cams on the half-time shaft located in the crank case. In a great number of instances the cylinder or cylinder head is provided with a port passage or pocket on one side of the cylinder head and the exhaust valve is seated therein with its stem projecting toward the crank shaft. The inlet valve may be similarly seated in a similar pocket, or in the same pocket with the stem projecting in the opposite direction. An advantage of having the inlet valve in the same pocket is that the incoming charge cools the exhaust valve and also the sparking parts, which are frequently located in the same pocket entering through the side thereof, or as in the Duryea, through the exhaust valve stem. It is evident that one pocket requires less cylinder wall than two and therefore loses less heat to the cooling system.

The size of the valves depends much upon the speed required and should be quite large if a high speed is desired. Very satisfactory practical results are obtained by making the exhaust valve one third the piston diameter and the inlet valve one fourth, although to save variety of parts, some designers use the same size valves in both instances, but do not lift the inlet valve so high. Variable lift valves are much in favor because this prevents unnecessary valve movement with consequent wear and noise. In some cases this variable lift is secured by introducing a wedge between two parts of the lifting mechanism, and in other cases by holding the valve against more than a limited lift in response to the suction of the piston, as in the variable lift inlet valves of the Duryea.

Auxiliary Exhaust. In order to get rid of the excess heat, and relieve the regular exhaust valve of part of its duty, some engines are provided with an auxiliary exhaust, consisting of a port through the cylinder wall uncovered by the piston at the end of the working stroke, as in the Fredonia and Franklin machines. It is considered advisable to provide this port with a check valve to prevent back pressure from the muffler from re-entering and lessening or possibly igniting the new charge; although this is probably not so necessary in single or double cylinder engines. Many designers consider the auxiliary valve as an unnecessary complication, used only where the regular valve is inadequate.

Muffler. Connected with the exhaust opening by piping of convenient length, is the muffler, consisting usually of several chambers generally cylindrical, and having walls of sheet iron. This device has usually several times the capacity of the cylinders, which permits the exhaust gases to expand considerably and exposes them to the cool walls, thus reducing their volume by cooling, so that as they escape to the atmosphere they make much less noise than if permitted to escape without the intervention of the muffler. Multiple passages as well as multiple chambers are usually provided, and the silencing



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effect seems to be largely derived from interference of the sound waves and gaseous impulses.

Most mufflers offer some back pressure, but if of sufficient size, and provided with three to six chambers, the exhaust of the ordinary auto engine can be silenced as effectually as other noises about the vehicle, with so little back pressure as to not be perceptible in the propulsion of the vehicle if a cut-out is used. Mufflers sometimes clog with soot and dust and do not permit free escape of the gases, particularly at high speed. The large part of the burnt charge remains in the cylinder and prevents the entrance of a new charge, with consequent failure to produce power. Muffler explosions are due to missed fires in the cylinders, which allow the unburned charge to pass to the muffler, where it is ignited by the next exhaust and explodes quite noisily, and sometimes to the damage of the muffler. Muffler cut-outs are often used on hills or where great power is needed, and they avoid any back pressure from the muffler.

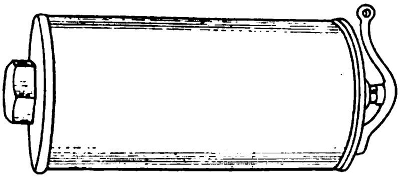


Fig. 16. Muffler and Cut-Out.

Vaporizers. Connected to the inlet ports is the device for mixing the liquid fuel, commonly gasolene, with the proper proportion of air to make an explosive mixture. Formerly this was done by a device for passing the air through the liquid contained in the tank, termed a carburettor, and while good results were obtained therefrom, it was more delicate and not so satisfactory to adjust for varying weather conditions as the devices now used. Present-day devices are modifications of the well-known atomizer used for perfume and medicine sprays, and might better be termed mixers or atomizers than carburettors. Since, however, the liquid after being sprayed, is intended to be vaporized before ignition, a common and correct term for this device is vaporizer. There are many modifications of this device but in general it consists of a small gasolene chamber in which the level of the liquid is controlled more or less perfectly, by a float, the chamber being vented so as to permit admission or abstraction of liquid without establishing a compression or vacuum.

From the float chamber a small passage, usually controlled by a needle valve, leads to the spraying tube, which is so placed that the air drawn in by the suction stroke of the engine must pass the point of the tube, and in passing, suck out and spray the gasolene in the required manner. In order to give the air greater speed and a more powerful effect, it is customary to make the air tube contracted at the point where it passes the spray tube, although very satisfactory vaporizers have been produced without this modification. Since at high speeds the liquid gasolene flows more than proportionately fast as compared with the air, it is quite common to provide a light valve, spring closed, to be opened by the increased suction as the speeds increase and to admit air in proper quantity to compensate for the increased amount of gasolene. This valve in some forms is actuated by a large dia-

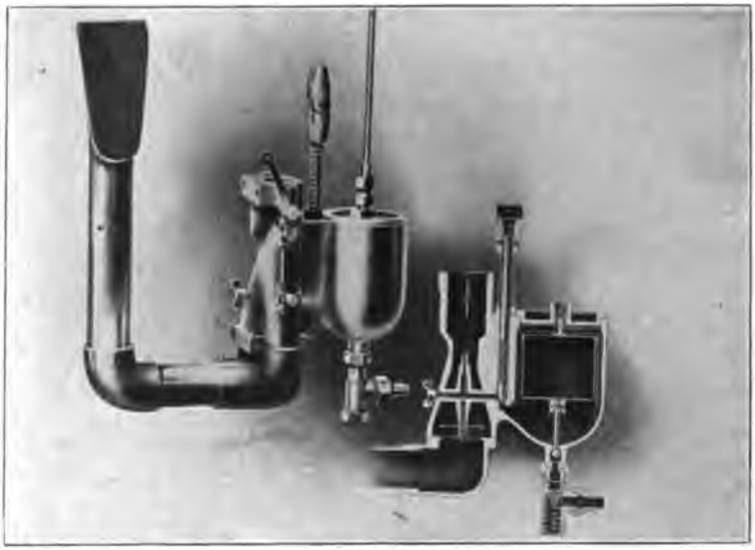


Fig. 17. Carburettor.

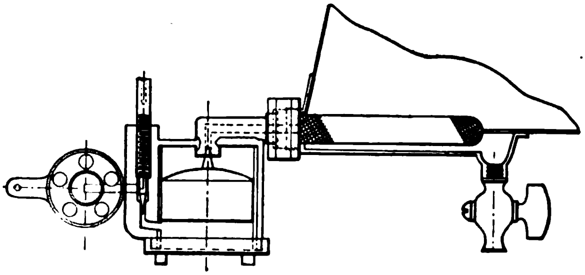


Fig. 18. Sectional View of Carburettor.

phragm, as in the Krebs, and is sometimes provided with a dash-pot.

In some vaporizers the air and gasolene openings are varied by the throttle, which is also varied to control the speed of the engine, and since the screw threads, or devices controlling the variation, may be made as desired, a fairly constant quality of mixture may be secured from vaporizers of this type, subject, however, to the fault that if the throttle is open wide but the engine running slowly, the adjustment intended for high speed will be in operation at low speed, and thus is not so satisfactory as an automatic suction-operated arrangement. The early Kingston carburettor was of the throttle-controlled type. In still another type, of which the Duryea is an example, the air-flow passes through an opening fixed in size except for starting, but the gasolene-flow is varied by lowering the level in the float chamber at high speeds. This is accomplished by the use of a chamber slightly larger than the float, so that little or no reserve gasolene is carried, and this is drawn out immediately at high speed, causing the float to fall and open the passage into the float chamber. The float is provided with a long taper point which requires a considerable movement of the float, in obedience to the considerable variation of the gasolene level, in order to supply the amount of fuel needed at high speed.

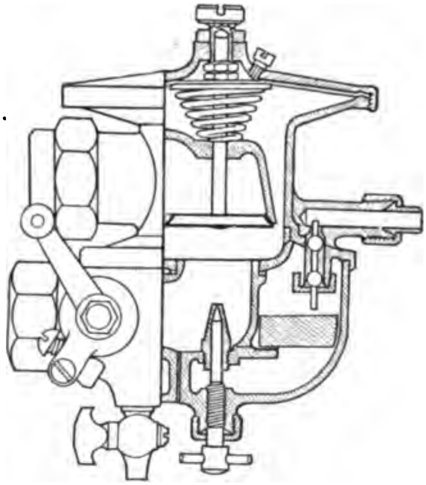


Fig. 19. Automatic Compensating Carburettor.

In still another form, invented by Dunlop, of pneumatic tire fame, the gasolene passage is impeded by a saw-toothed wire, against which teeth the gasolene, at speed, impinges with such violence as to obstruct its flow and lessen the amount passing from the spray tube. Still another form of mixing device does not use the float chamber, but admits the air and gasolene through proportionate valves closed by a spring and opened by the suction of the motor with consequent admission of proportionate amounts of liquid and air. The original Winton and the Lunkenheimer generator valves were of this kind.

Vaporization. The vaporization of a liquid requires heat, which, in the case of a gas engine vaporizer, is usually obtained from the air with the result that the temperature is decidedly lowered where the vaporization takes place, viz., between the spray tube and the engine, principally near the spray tube. If the atmosphere contains much moisture, this cooling effect causes a deposit on the walls of the vaporizer or its tubing, which is frequently frozen, forming slush or white frost, sometimes to such a degree as to actually close the passage and prevent further formation of proper mixture, with consequent stoppage of the engine. To prevent this and to insure a more homogeneous mixture, heat is usually supplied by drawing the air from near some heated portion such as the exhaust pipe or exterior walls of the cylinder, or by applying heat to the outside of the vaporizer or pipes by directing some of the exhaust gases against them, or by surrounding the parts with warm water from the water jacket. No method secures absolutely perfect results, for atmospheric conditions vary so widely from day to day that only constant readjustment can meet the varying conditions.

Vaporizer troubles are usually due to improper adjustment, the mixture being either too poor or too rich. If the engine will run, the adjustments can be varied and the result noted, while over-rich mixtures will be quite apparent by the odor of carbon monoxide in the exhaust. If the engine will not run, test the mixture in the cylinder by removing a spark plug or peep cap and applying a flame, being careful not to get fingers or face in front of the opening. If the mixture burns bluish with little violence, it is too poor, but if it burns yellow and slow, it is too rich. A proper mixture explodes with a violent outrush of gas.

Frost in the air tube will so obstruct the passage as to prevent the entrance of a new charge and produce loss of power much like a choked muffler. A little hot water will quickly warm the pipe. Water or ice in the gasolene will cause trouble unless removed. The water frequently manifests its presence on rough roads, and a drop of water in a passage—which will not obstruct the flow—has, when frozen, completely shut off the gasolene. Dirt particles also must be guarded against.

Excess Cooling. Since the auto engine is a heat engine it is desirable that it be as hot as is permissible, in order that the heat may be utilized for work instead of passing into cold walls and being wasted. It is well known that a cold engine runs with little power until warmed up, and while part of this lack of power may be due to the stiffness of the lubricating oil,—since this is intended to resist a high heat and must be of high fire-test and of considerable body—much of the lack of power is due to the cooling effect of the cold walls, which absorb the heat from the burning explosive charge and reduce the pressure that, with hot walls, would be expended in doing active work against the piston. Tests have been made which show that a very perceptible increase of power results from the use of hot water for cooling instead of cold water, and stationary engineers who have permitted a flow of water through the water jacket so rapid as to keep the jacket and walls cool enough to not be uncomfortable to the hand, have found a very decided increase in power when the water was caused to flow more slowly and leave the jacket substantially at the boiling temperature.

It is now generally admitted that a temperature slightly below boiling is most satisfactory where water is used for cooling; for if the water does not boil, no steam is formed, and no parts in the water jacket are left without water, with possible danger of overheating. These facts, now well-known, prove the theory that a heat engine should be run hot in order to give most efficient results, and it is the aim of designers to so design their productions that no parts shall be over-hot but that all shall have as high a temperature as is permissible. The principal limitations are premature ignition and faulty lubrication.

Premature Ignition is objectionable because of the negative work done on the piston before it passes the dead center, which not only results in lost power, but usually in a decided knock or pound, annoying to the passengers and destructive to the bearings. Since a poor mixture ignites less easily than a rich one, premature ignition can be frequently lessened and sometimes avoided by varying the quality of the mixture—a proceeding which also adds to the economy. Since compression heats the explosive charge, nearly proportionate to the amount of the compression, an engine designed to run hot should have a large compression space with consequent low compression. The increased economy of the less rich mixture in conjunction with the hot cylinder walls largely balances the loss of power, due to the lessened compression and since the engine with low compression runs steadily with a smaller fly-wheel, there is a perceptible saving in weight in a motor vehicle and consequently less need of power.

It is also apparent that with a high compression and a small compression space, the pressure at the beginning of the stroke is very high but falls rapidly because the length of the stroke is quite large as compared to the size of the compression space, whereas with a low compression the initial pressure is not high and the compression chamber is of large volume as compared with the length of stroke, so that the pressure is reduced less rapidly and the result is more nearly like that given by a steam engine than is the action in a high compression cylinder.

Because of these facts a low compression cylinder, rather large for the power required, but because of the low compression, light in all its parts, including fly-wheel, and designed to run comparatively hot, is considered best for auto work by many good authorities. It has been frequently noticed that an air-cooled engine, will, for a short period, develop more power than a water-cooled, and this is explained by assuming that the walls become much hotter than the temperature of boiling water, on which account the engine is more efficient up to and until the point of overheating is reached. After this, loss of power occurs, either because of premature ignition or lack of lubrication, or possibly, because at very high temperatures, the cylinder walls or the piston warp sufficiently to no longer fit each other and thus permit the escape of the gases with consequent loss of power. While higher temperatures may be with advantage used in future, it seems safe to assume that in the present state of the art, a temperature not greatly in excess of boiling water, is most preferable in present auto engines.

Lubrication. Faulty lubrication of an engine cylinder may be due to the improper fire test of the oil, to improper methods of applying the oil to the surfaces requiring lubrication, or to improper fits between those surfaces, which permit the escaping gases to blow the oil away from the surfaces, leaving them dry and therefore increasing their heat, both by the friction of the nonlubricated parts and by the heat of the escaping gases which is absorbed by the parts. It is now pretty generally recognized that auto cylinders require oil of the highest quality, and that cheap and dirty oil sometimes sold as gas engine oil, is not suited for this work.

An oil suited to steam engines using superheated steam, will in almost all instances, give excellent satisfaction in auto engines. The makers of the vehicle will gladly advise what oil should be used in connection with their product, and when a good oil is once found, it is wisdom to continue its use. If an oil is too thin it does not protect the metal surfaces properly and does not make a good packing nor properly assist the rings in holding the pressure. If of too low fire-test, it boils away as a blue smoke or vapor and leaves the surfaces dry, frequently causing them to cut, and sometimes ruining the cylinder or stopping the motor. A sudden loss of power without apparent cause may, with good reason, be looked for in the cylinder, since lack of lubrication makes a great difference in the friction of the piston, even though the parts are not cutting or have not seized. An excessively thick oil with needlessly high fire-test has no disadvantage except that being stiffer when cold, the engine is more difficult to start. Such oils are decidedly more economical because they wear longer and need be fed less rapidly. Good auto oils usually have fire-tests ranging from 600 to 800 degrees.

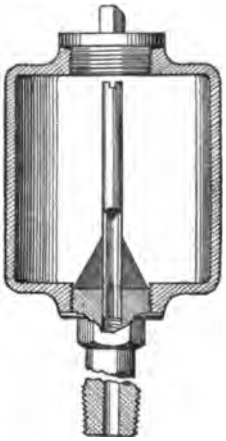


Fig. 20. Lubricator.

If for any reason, proper oil cannot be had, an oil of lower fire-test can frequently be used, but it must be fed in larger quantity and more carefully watched to make sure that it is serving its purpose.

Water Cooling. Consideration of the above facts will show the importance of proper cooling, and something of the loss due to excessive cooling. In a water-cooled engine, the water being unconfined, cannot become hotter than 212° and may, with little trouble, be kept nearly at this point, which is admitted to be most satisfactory, so far as present experience goes. Further, since water in boiling absorbs a great volume of heat, commonly termed latent heat, in its conversion into steam, it is especially adapted to the work of cooling. An increase of work on the part of the engine, with consequent increased development of heat, simply increases the rate of boiling without increasing the temperature appreciably, and thus avoids warping the cylinder wall or vaporization of the lubricating oil.

A most efficient cooling system consists of a tank or reservoir of water above the engine, piped to enter the water jacket on the underside and to return from the water jacket to the tank on the upper side of the engine, which return carries off any steam that may be formed in the water jacket, which steam being lighter than the water, causes the water with which it is mixed to move rapidly upward out of the water jacket and to be replaced by cooler water from the tank. This method of circulation is known as the natural or thermo-syphon method, and is preferred by many designers because of its simplicity. When it is not convenient to use natural circulation, a pump, driven by the engine, is introduced in the circuit and forces the water rapidly enough to nearly or quite prevent boiling under extreme conditions. A forced circulation, however, is not so good as the natural because it is not self-regulating, and therefore if it is fast enough to meet the needs of the engine under extreme conditions, it is usually too fast under ordinary conditions, and results in keeping the temperature of the water in the water jacket much below the boiling point and therefore below the point of greatest efficiency.

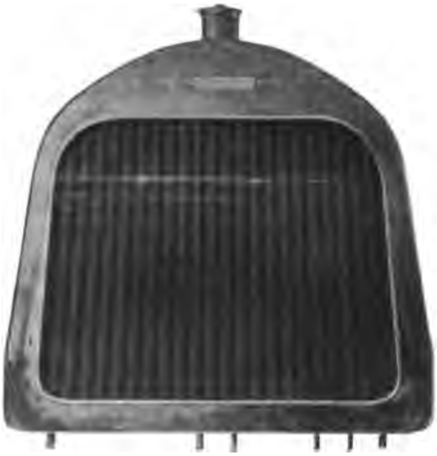


Fig. 21. Radiator.

To overcome this objection, some designers employ natural circulation between the engine and the small tank located near and above it, and employ a pump with radiator for the purpose of preventing the water in the tank from getting too hot to condense the steam that may pass into it from the engine. This arrangement gives the benefit of both systems with but little, if any, increased complication.

Since an auto engine of large power develops much heat, a goodly quantity of which passes away through the cooling system, it is quite evident that the water in the tank will soon become boiling hot unless provision is made for cooling it by the air through which the vehicle passes. It was formerly quite common to provide the tank with air tubes, thus greatly increasing the amount of surface exposed to the air and permitting a more rapid escape of the heat. Other designers employ pipes either plain or with radiating fins, so as to still more largely increase the radiating surface exposed to the air. Still others make their water tanks almost wholly of air tubes, with very small water spaces between, thus getting into a small radiator a great many square feet of cooling surface. In this form of radiator it was found that the natural circulation of the air is very slight because of the small size of the passages, so fans driven by the motor are most frequently used to either draw or force the air through these radiators at a rapid rate and with great cooling effect.

A further advantage of the air-fan in connection with the radiator is that the cooling is not dependent upon the speed of the vehicle nor the force of the wind but is varied by the speed of the motor, and therefore more nearly meets the needs of the motor than any other system excepting the natural system, first mentioned. If for example, as in hill climbing, the motor is running slowly, but with full charges, much heat is developed, but the fan also moves slowly, with very little cooling effect, whereas in the natural system, until the water begins to boil, the circulation is very slow and the more rapid the boiling, the more rapid the circulation becomes. This results in a truly thermostatic circulation, regardless of motor or vehicle speeds, due to the difference in density of the cool water in the radiator and the hot water containing more or less steam in the jacket which is sufficient to meet the requirements of some engine designs. In others, a pump to circulate the water is used.

There have been employed steam condensers in connection with the water jacket by which arrangement no water tank nor pump is needed, because the slight amount of water in the jacket when turned to steam, is condensed by the condenser and at once returned to the jacket. Practically all water-cooled engines form steam at some time, which, not being provided with suitable condensing surface, escapes from the system, thus requiring occasional addition of water. It is considered advisable to have a tank of water above the cylinder jacket, so that the cold water may condense this steam and also always keep the cylinder filled. This tank carries from two to ten gallons.

Most radiators are tubular and on the tubes are fitted and soldered disks of metal, which serve to conduct the heat from the water out to the air, which, by the passage of the vehicle, is thrown against the metal surfaces. These flanges are formed in some instances by crimping a strip of metal along one edge and winding it spirally around the tube, the crimped edge being soldered to the tube. This avoids waste of metal and makes a very efficient radiator. The height of the disk edges above the tube is usually ¼ to ½ an inch or about 10 to 20 times the thickness of the metal, the smaller sizes being most efficient.

In some cases the water tank is cooled by tubes passing through it, which permit a flow of air. These tanks vary from those of large water capacity, having a half dozen or more one-inch tubes, to tanks of small contents completely filled with tubes, either square or round, ½ inch in diameter or less, by 3 or 4 inches long. Such a device is called a cellular or honeycomb radiator, because the tubes suggest the cells of a honeycomb. This type of radiator contains a very large cooling surface, divides the water into thin sheets and is quite efficient, but it is expensive to make, has many joints likely to leak, and the fine passages are easily clogged, on which accounts, the tubular form is now generally preferred. The tubes may be continuous, causing the water to travel the whole length, but later forms use a number of tubes connected at their ends by heads or top and bottom tanks, and the water flowing from one end to the other, is divided, so that a small portion only flows at slow speed through each tube. This arrangement relieves the pump of much of its duty.

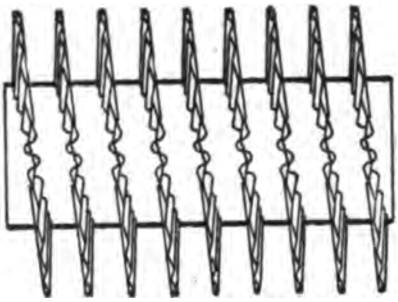


Fig. 22. Radiator with Spiral Flanges.

Air Cooling. Since in any event the heat is dissipated into the air, it is argued by many that air cooling is the most logical form, and many attempts have been made to produce successful air cooled motors. The total heat in the burning charge varies as the cube of the cylinder dimensions, whereas the wall surface varies only as the square; so it has been assumed by many that large engines are of necessity more difficult to cool than small ones, and that air cooling, while applicable to small powers, is not suitable for larger ones. Others maintain, while admitting the above statement as to the total amount of heat, that the heat received by the wall from the gases in the engine must come from the gases adjacent thereto, and that on this account the wall will be little, if any, hotter in the one case, than in the other, and that large auto engines can be cooled just as readily and practically as small ones.

Since, however, the size of engines used in auto work is limited by the weight of the parts and the intensity of the vibrations set up by the explosive charge, it seems quite likely that the latter contention is practically true. It is now no longer common to increase power by increasing the bore of the cylinders, but the accepted method is to increase the number of cylinders, and it was quite thoroughly demonstrated by Knox and others, that cylinders up to 5 inches bore, of varying strokes, can be successfully air cooled.

The most common forms of air-cooled cylinders are either cast with flanges encircling them or machined out of a solid body of stock or forced on by pressure after the cylinder is machined. Other forms have the cooling flanges cast lengthwise of the cylinder. If the engine is horizontal the encircling flange permits the hot air to pass freely away, which is not the case when the engine is placed vertically, unless a fan or some means for moving the air horizontally is provided. For vertical engines using natural air circulation, the lengthwise flanges are undoubtedly best.

Many air-cooled engines are fitted with special forms of cooling surfaces such as threaded pins having one end screwed into the cylinder wall, which pins not only carry the heat outward, but because of the screw threads on their surfaces, are in contact with a large volume of air. Grooves are frequently machined into the cylinder surface, in which are chalked combs or strips of radiating metal having large radiating surface.

In all the larger motors, fans are used to direct a current of air past the radiating surfaces to insure effective cooling.

In some engines, as in the Frayer-Miller, the cylinder is enclosed in a jacket, through which air is forced and by which the air is caused to come in close contact with the heated surface with the result that the cooling is positive, is certain to be effective where needed, and is largely proportioned to the needs of the engine, because the blower which supplies the air is driven by the engine. In air cooling, however, unlike water cooling, there is no fixed temperature point and there is, therefore, much more variation in the walls of the cylinder, with consequent possible warping, than is found in a water-cooled motor. This variation is believed by many to shorten the life of the engine and increase its troubles, while others argue that the avoidance of the water system more than makes up for the lack in this respect.

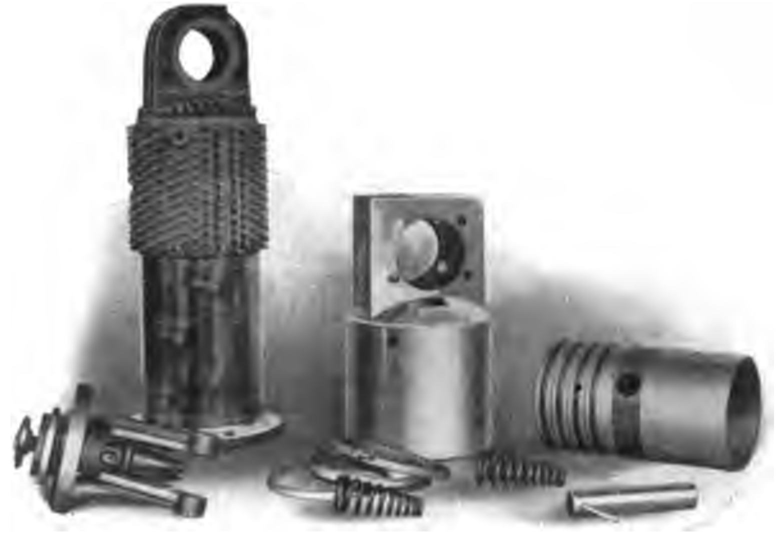


Fig. 23. Frayer-Miller Engine Parts.

The aluminum jacket slips down over the cylinder head, the valves being put in from opposite sides. Air is forced down from the top of the jacket passing equally to all sides, cooling the cylinder without warping.

CHANGE-SPEED DEVICES

Second in importance only to the motor is the mechanism for conveying its power to the rear axle, or to the propelling wheels. This mechanism consists usually of first, a change-speed device by which the ratio of motor revolutions to rear-wheel revolutions is varied to meet the varying road conditions, such as hills, mud, sand, snow, crowded traffic or clear level roads; second, of a transmitting device such as a shaft, chain, or chains, or belts between the change-speed gear and the rear wheels; and third, of a balance gear often called a differential, or its equivalent, by which the power is divided and caused to drive both wheels, while permitting freedom for the purpose of turning corners.

Change-speed gears are of many varieties, of which the most common are planetary, sliding gear, individual clutch, friction, automatic and several others, combining more or less of the various features found in these forms with possibly slight variations, such as magnetic, pneumatic or hydraulic clutches. Few subjects offer a greater field for ingenuity than change-speed devices, and many forms not worthy of description in the limited space available, have been tried and found reasonably satisfactory.

Planetary Gear. The planetary gear was the first form to be largely used in America, being first regularly employed on Duryea vehicles in 1898 and afterward adopted in the Olds runabout and by its many imitators, as well as in the Cadillac and Ford machines, in all of which it is still found, as well as in many others. In its original form it employed a spur driving gear attached to the crank shaft. Meshing into this was a planetary pinion carried by a stud projecting from a frame journaled on the crank shaft end, which frame carried the driving sprocket. Meshing into the pinion, was an internal gear concentric with the crank shaft, and the device was provided with three clutches, one for locking the parts together, so that all would revolve with the crank shaft, forming direct drive on the high gear; another for holding the internal gear stationary while the pinion rolls around inside it, carrying the sprocket forward at low speed; and a third for holding the pinion frame and causing the sprocket to be carried by the internal gear in a reverse direction as the pinion revolves. (The sprocket having been first released from the pinion frame.)

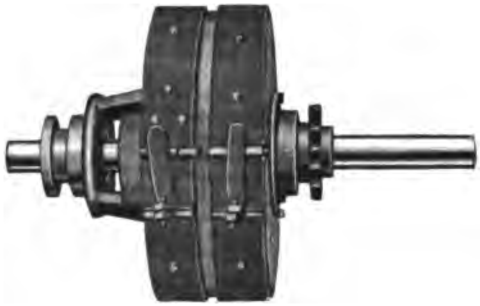


Fig. 24. General View of Planetary Gear.

These clutches were operated separately, only one, as a rule, being engaged at a time. A single operating lever was usually employed for high and low speed, while a second lever was used for the reverse. Two to four pinions were employed instead of one, which gave added strength without requiring additional room, and thus permitted the gears to be of much narrower face for a given duty than would have been possible with a single form. Modifications of this device employing two or more sets of gears are largely used because the original form was protected by patent, but the principle is much the same in all. The diagram herewith illustrates the action more fully. As usually constructed, the planetary system provides two speeds forward and a reverse, but some forms provide for three speeds forward together with a reverse.

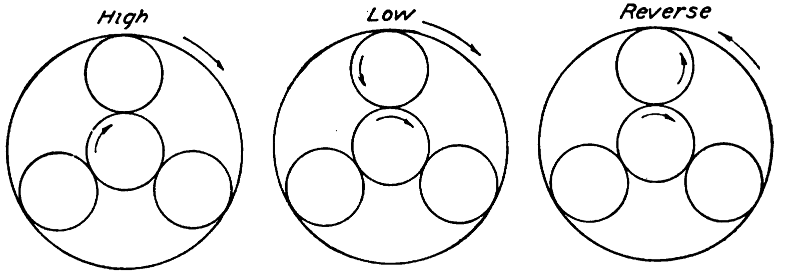


Fig. 25. Planetary Gear Diagram.

All parts locked together, gives high gear and carries the sprocket at same speed as crank shaft without friction or moving parts.

Holding the large internal gear causes the intermediates to roll forward slowly and carry the sprocket with them, giving low gear, one-third to one-fourth the crank shaft speed.

Holding the spindles of the intermediates drives the internal gear in a reverse direction, giving the reverse speed.

Individual Clutch. The individual clutch transmission is still an older form, having been used by Duryea in '93, Haynes in '95 and by several foreign makers fully as early. This consisted usually of two parallel shafts on which were two or more sets of spur gears of different sizes but of a common distance between centers. Each set of gears was provided with a clutch adapted to cause that set of gears to transmit power at its proportionate speed when desired by the operator. For reversing purposes, sprockets and chain instead of gears were used, or one set of gears small enough not to mesh, but provided with an intermediate, were employed. The individual clutch system permits a wide variety of speeds, smooth and noiseless engagement of any speed, and is a very satisfactory system, its principal objection being the large number of clutches and the fact that all sets of gears are in motion at all speeds. To avoid clutches some designs employ a single friction clutch and a movable key or pawl by which any gear can be locked to the shaft, and speed changes are made by sliding this key from one set of gears to the next. The strain on the small key results in its rapid destruction and forms the principal objection to this arrangement. Similar results are obtained by sliding the gears themselves, which although not so compact, is considered a stronger and more desirable device.

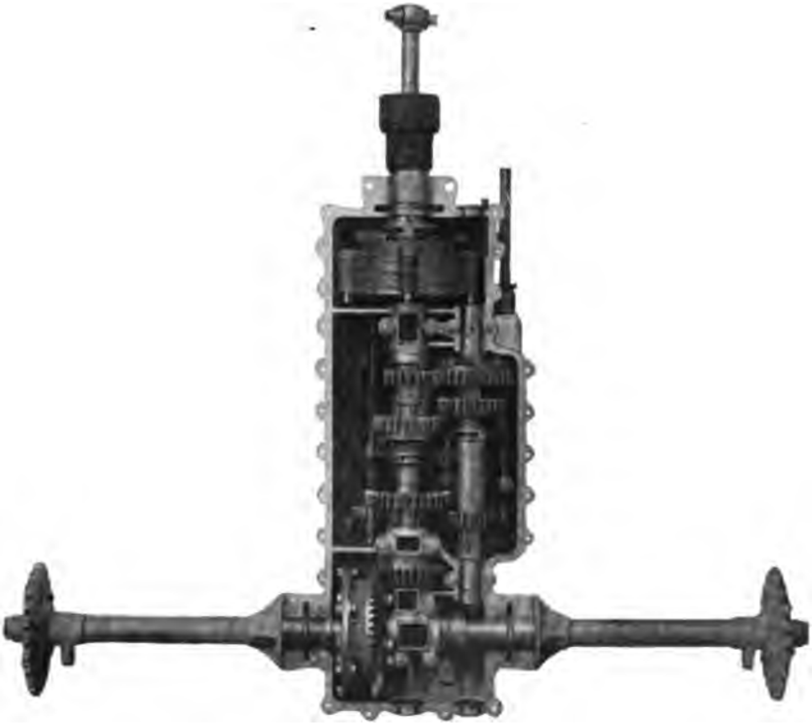


Fig. 26. Clutch, Sliding Gear and Counter Shaft.

Sliding Gear. Possibly the most used form to-day is the sliding gear. This, like the other forms, is made in a number of varieties but, in general, consists of parallel shafts, and multiple sets of gears of differing proportions. On one shaft the gears are fixed, while on the other they are commonly attached to a sliding sleeve, which is either fitted to a square shaft or provided with a spline and key-way to prevent rotation of the gears without rotating the shaft, and yet permit free movement of the gears along the shaft. The gears are placed at such intervals that when one is engaged, the others are disengaged. In operation, a single clutch, generally located in the fly-wheel, is withdrawn while the gears are being shifted, after which the clutch is allowed to engage and propel the vehicle. The ends of the gear teeth are sharpened so that they will engage each other easily and thus permit shifting from one set to another without difficulty. If the clutch is not fully withdrawn, the ends of the teeth about to engage, strike against each other, often making considerable noise and sometimes breaking the teeth.

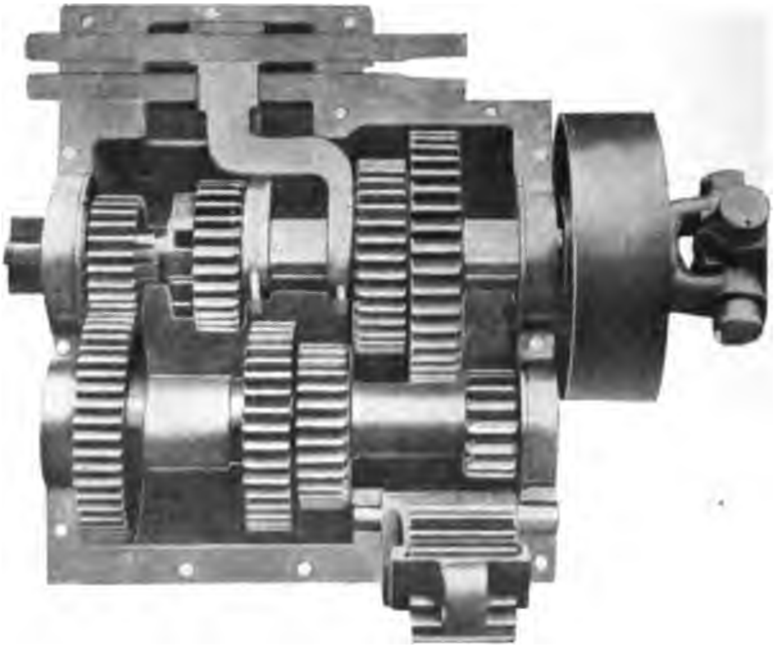
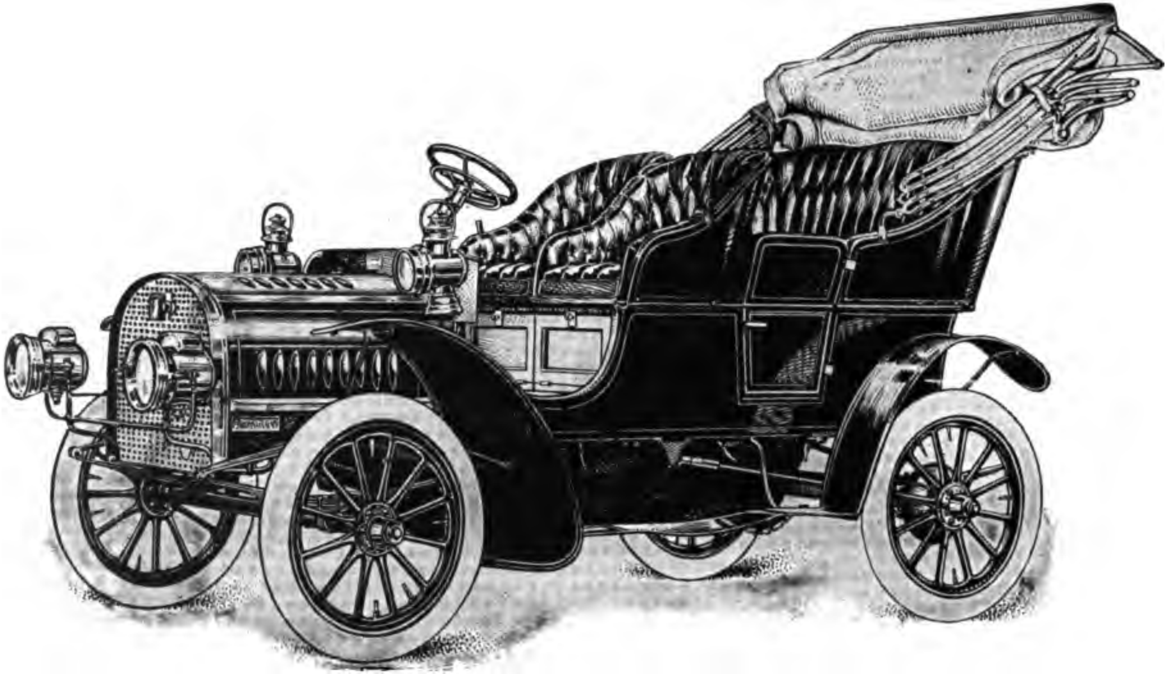


Fig. 27. Sliding Gear Set.

In the better forms of sliding gear designs, the main shaft is divided in a gear box, and the power transmitted to the second shaft is, by an additional set of gears, returned to the second part of the main shaft and by it transmitted to the wheels. At one speed, usually the highest one, the two parts of the main shaft are connected by a clutch of the positive or jaw-clutch variety, while the parallel shaft with its gears is completely disengaged and stands idle. This gives a direct



SURREY TYPE OF RAMBLER AUTOMOBILE
Thos. B. Jeffrey & Co.

drive, free from needless friction and is considered quite advantageous. In some forms, two of the sliding gears are on one side and two on the other. This, of course, requires two shifting forks in its operation. Other forms employ a shifting fork for each gear and a selective means of engagement by which the operator can cause the single shifting lever to engage any desired fork, and thus put into operation any gear which is brought out of operation as the lever passes to neutral, where it is again ready to engage any desired gear.

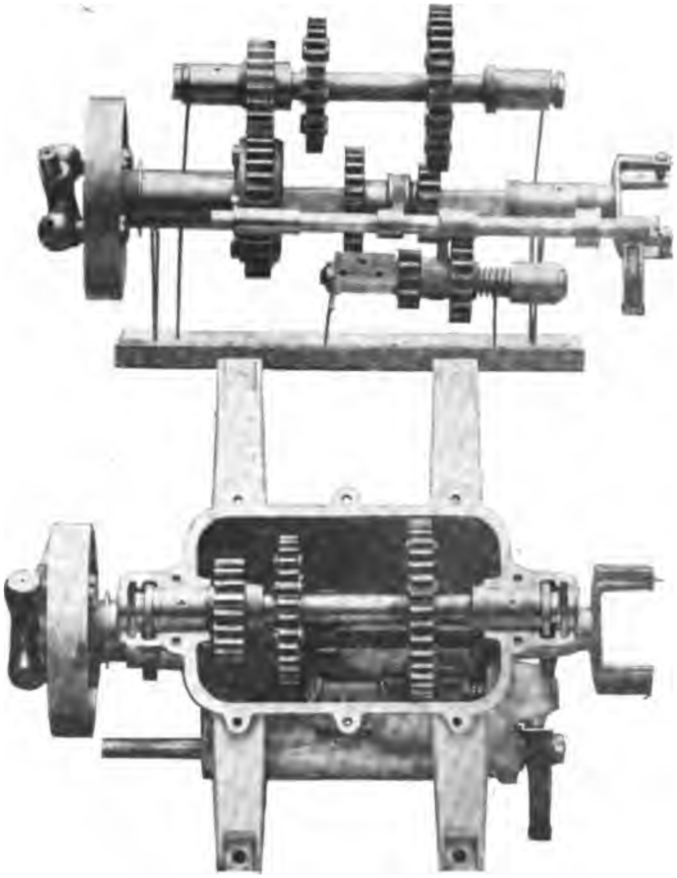


Fig. 28. Sliding Gear Transmission.

The objections made to the sliding gear device is that this method of meshing gears is unmechanical, wears the gears rapidly, is likely to break them, and the means of shifting is much slower and therefore less safe and handy than the individual clutch or the planetary systems. It is argued, for example, that in the sliding gear the operator must withdraw the clutch, then withdraw the gear, then shift the gear lever, then cause it to engage a different gear and finally complete the operation by letting in the clutch–a total of five movements. In the planetary device the same motion that withdraws the high clutch will, if continued beyond the neutral point, engage the low one and vice versa, while in the individual clutch system one movement disengages the clutch and another, usually of the same lever, engages another clutch, with its corresponding gears; at most two movements, and in many forms accomplished by a single movement.

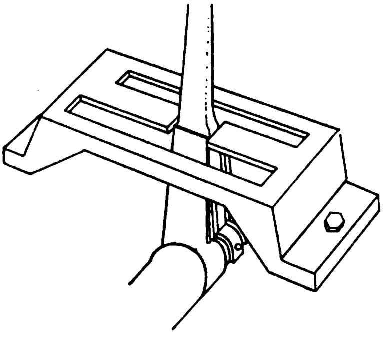


Fig. 29. Single Lever Quadrant, Selective Type.

The importance of quick action in a crowded street or on a steep hill can hardly be overestimated, particularly since motor vehicles are rapidly-moving devices and but little time can be allowed for the performance of any simple function like speed changing. In spite of this disadvantage, however, the sliding gear seems to be increasing in popularity, which is probably due to the fact that many people regard the foreign vehicles as superior to the American, and the sliding gear is a foreign device. It seems also probable that the greater simplicity of the sliding gear system as compared with the individual clutch has caused it to find favor with the makers, to whom simplicity means cheapness, and who are not so much concerned as to whether or not it is most easy to operate. The simple device is not only cheapest for the manufacturer but it is generally more easily understood and maintained by the owner, and should, if other things are reasonably near equal, be given preference.

Friction Gear. The friction gear, although but little used, is an exceedingly old form. It was probably the first form in the thought of every designer in connection with the gas engine, for in the early days gas engines were regarded as being inflexible, and a flexible driving gear was considered an absolute necessity. Lack of positiveness, the objectionable pressure necessary to secure driving friction, the disturbing effect of grease, frost or water when found upon the friction surfaces, the large size of the discs required, and the constant loss of power due to the fact that variable friction devices cannot be constructed upon rolling cone lines, all conspire to make friction devices objects of suspicion to which most designers were unwilling to confine their efforts. Successful use for many years upon vehicles of even the heaviest weights has proved that friction driving gears are capable of successful use and excellent service, and that their advantages and objections compare favorably with other systems.

Several forms have been used, of which the most common form, and the one longest in use, consists of a disc on the engine shaft parallel to the plane of the fly-wheel and often formed by the fly-wheel itself. Parallel to this disc is a driven shaft on which the driven disc is arranged to slide with its edge in contact with the face of the driving disc. This driven disc can be shifted from the extreme outer edge of the driving disc, which is usually high speed position, to a position which is beyond the center of the driving disc, which is a reverse position. At the center the driving effect is nothing and the driven disc would stand still but is usually disengaged at this point. This form has been in use for five years on Union vehicles and has been thoroughly tested under every condition of road service.

A modification employs two additional discs, one journaled on the cross shaft with its edge engaging the reverse surface of the driving disc, the other journaled independently on a short shaft in line with the driving shaft and with its outer surface engaging the edge of its mate, while the driven disc engages its face opposite the point of engagement on the driving disc. This arrangement applies power to the driven disc at opposite sides, which balances the pressure and increases the driving effect to a considerable extent.

A modification of these forms reverses the positions of the discs and employs the shifting disc as the driving device with its edge moving across the surface of the driven disc. This reversal secures great power at low speeds, but for pleasure motor vehicles this is not so desirable, for they are usually driven on the high gear, depending upon the throttling of the engine for necessary variations in speed, and friction discs of this arrangement are quite wasteful of power when the transmission point is near the center of the disc surface. This is because of the fact that the point of contact is not actually a point, but covers a considerable surface, on which account a considerable slip and loss of power results. This slip is dependent both upon the width of the friction edge in contact with the disc and upon the curvature of that circle of the disc in contact at any particular time.

If we assume the contact surface to be more or less elliptical in shape, it will readily be seen that the surface must necessarily slip in opposite directions on opposite sides of the center of the contact area, and that this slipping is both across and with the edge of the driven disc.

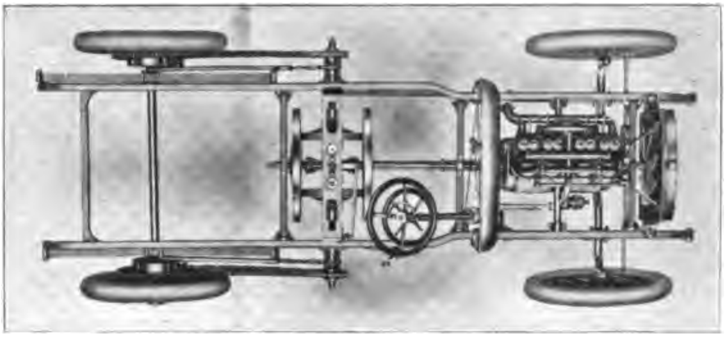


Fig. 30. Evansville Friction Drive.

A third form of friction in use on Evansville vehicles is a modification of the second form. In this the driving shaft is equipped with two discs between which is placed two halves of a cross-shaft, each equipped with two edge-driven discs. These half shafts are so mounted that their adjacent ends can be thrown in opposite directions and the discs on them are likewise mounted to move oppositely and in like proportion. Since the driven discs are on opposite ends of the driving shaft, it is obvious that if one is thrown forward and the other backward, both will be rotated in the same direction, whereas if they are thrown in the opposite direction a reverse motion will be given. This obviates passing the center of the driving disc to secure a reverse, and since it is seldom or never necessary to have an extremely slow speed, the driven discs need not be shifted greatly to produce the variations in speed, which is done by shifting them toward or from the other edges of the driving discs. The illustration makes the arrangement plain without further explanation. The amount of clearance is so slight that the movement of the half shafts out of a direct line is too little to have any practical effect of a detrimental character.

A fourth form is arranged to make use of the friction drive only for such variations in speed as are necessary below direct drive, and secures the advantage of direct drive without loss for high speed work. This arrangement seems particularly adapted to pleasure vehicle service and will doubtless find large adoption in future. In this construction the driven disc stands parallel to the fly-wheel and is shiftable toward and from the fly-wheel surface. The edge of the driven disc engages the plane surfaces of two or more intermediate discs, journaled on short shafts parallel to the plane of the fly-wheel. The edges of these intermediates engage the fly-wheel by gear or friction as may be,

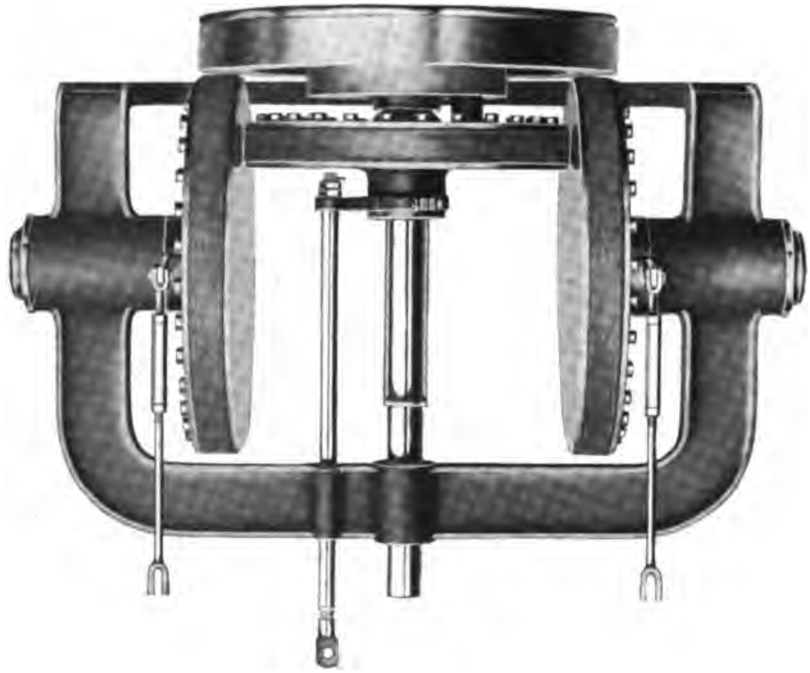


Fig. 31. Friction Drive for Variations in Speed below Direct Drive.

and transmit power to opposite sides of the driven disc. Shifting from the center of the intermediates toward the fly-wheel increases the speed, while in the opposite direction beyond the center gives the reverse. When near the fly-wheel a clutch is engaged, which connects the fly-wheel and driven disc positively after which the intermediates are disengaged, leaving direct drive on the high gear.

VEHICLE CONTROL

With all these devices the operator is called upon to perform certain operations, such as setting and releasing clutches, shifting the discs in and out of contact, or shifting and selecting the gears to be used. In the operation of the vehicle, he must have in mind the important function of speed changing, in addition to the equally important ones of steering and throttling the motor, together with minor functions such as spark management, lubricator oversight, and tooting the horn or sounding a gong, which is frequently required by law. Such a multiplicity of duties is confusing to many operators accustomed only to drive a gentle horse, which requires but guiding and speed regulation, and there is no doubt but that many accidents are due to the operator in an emergency becoming confused and failing to do the right thing to prevent trouble.

It is, therefore, quite necessary that vehicle control should be as simple as possible, and while some designers have eliminated minor details, such as spark control, and the necessity for watching the oil or water circulation, and have reduced the operation of the vehicle to steering and throttling, with sufficient power to drive a large and flexible engine almost wholly on the high gear, and without speed changing, others have eliminated speed changing entirely by making it automatic. Thus in the Sturtevant machines, the fly-wheel is provided with two or more sets of governor weights. When the engine is throttled extremely low, these weights are all drawn in by springs and all drives are disconnected, leaving the vehicle standing still. If the motor is speeded up, the lightest set of springs permit one set of weights to throw into engagement the low speed gears, and these continue in engagement until the vehicle attains considerable speed, when a second set of weights throw out, bringing into action a higher gear, which drives the vehicle at a higher speed. The lower speed gears become inoperative because of a ratchet provision which permits over-running the low gears, whenever the driven part acquires a speed above that imparted by the low gears. If the speed decreases, the high speed weights are drawn in by their springs and the low gears take up the work, until, as when stopping, they too become inactive because of lack of speed. This arrangement eliminates speed changing entirely and renders the vehicle more suited to the use of every member of the family than are most vehicles—a condition that sooner or later must come to pass.

Combination. In a few vehicles the motor has been used direct connected to a dynamo to generate electricity, which, either through a storage battery, or direct to a motor, is used to produce the necessary speeds. This system has not been largely applied to pleasure vehicles, but has seemed best adapted to commercial vehicles where, because of widely varying loads, widely varying powers are needed, and the electric motor not only provides a steady application of power, but in connection with the storage battery, is capable of great exertion for short spaces of time, and undoubtedly does give an almost ideal method of speed changing. The added cost and weight of a double system of this kind is quite likely the chief argument against it.

It has also been proposed to use pumps for water or oil directly attached to the engine, while a motor adapted to be driven by liquid was directly connected to the rear axle. Such a device, while doubtless flexible and smooth running, is admittedly inefficient and not easily maintained in proper working condition.

CLUTCHES

Since the gas engine must be started from an outside source, and runs with but little power when cold, it is practically necessary to have a clutch by which the engine can be disconnected from the driving gear or at least from the propelling wheels. The forms of these clutches are quite varied. In connection with the sliding-gear change-speed device the clutch is usually placed between the fly-wheel and the change-gear box and is generally of the conical variety, one member forming part of the fly-wheel and the other being attached to the shaft entering the gear box. One surface is usually faced with leather or similar material having a high friction coefficient, and a strong spring is arranged to hold the members in engagement. A pedal like a brake pedal is usually provided to withdraw the driven member, with a ratchet for holding it withdrawn while the motor is being started.

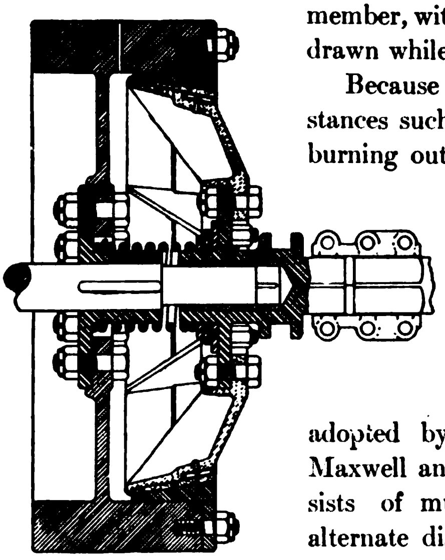


Fig. 32. Conical Clutch.

Because of the rapid wear of soft substances such as leather, and the danger of burning out the clutch surface in a few minutes after a clutch begins to slip, as well as because of the objectionable size necessary to secure an effective clutch of this kind, a better form of clutch has been recently adopted by leading makers, such as the Maxwell and Stevens-Duryea. This consists of multiple discs of metal, each alternate disc being attached at its edge to the driving member and the other discs attached at their centers to the driven member or vice versa. Light springs cause these to separate sufficiently to be clear of engagement when the clutch is released. The total amount of surface is so large that the friction coefficient may be very small. This form of clutch generally runs in oil, has no appreciable wear, needs no adjustment and the very worst that can happen is to burn out the oil between the discs and thus greatly increase their friction coefficients.

A very common form of clutch consists simply of a band, frequently lined with leather, vulcanized fiber, or even canvas, which is provided with means for causing it to grip the surface to be held. This form is commonly used in connection with planetary gears and is much employed as a brake device.

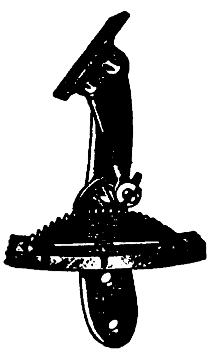


Fig. 33. Pedal and Ratchet.

In another form of clutch the surface to be gripped is not on the outside, as with the band, but is an inner circumferential surface, and two or more shoes or short segmental sections are caused to press against this inner surface by toggles operated by a collar shifted lengthwise the shaft. This is one of the earliest forms of individual clutches, and was used by Fawcett in an omnibus driven by an internal combustion engine at Pittsburg in 1876. A great variety of modifications of the devices just described are to be seen in use to-day, but with a knowledge of these most important forms the modifications are easily understood upon inspection. Square-jaw or positive clutches are used in some instances, as in the White steamer or the Chicago friction drive, and serve to change the speeds. Such clutches are used in some change gears instead of sliding the gears.

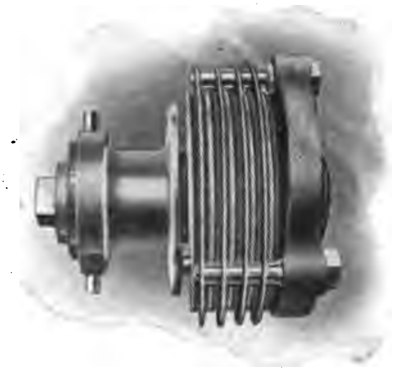


Fig. 34. Multiple Disc Clutch.

TRANSMISSION

After passing the change-speed gear, the power is transmitted usually to the balance gear, and for this purpose the single chain is the most common form. This is so simple as to need but little description, being known in its simplest and most successful form on practically all bicycles. The front or driving sprocket is usually small, the larger or driven sprocket being several (three or four) times the diameter of the front.

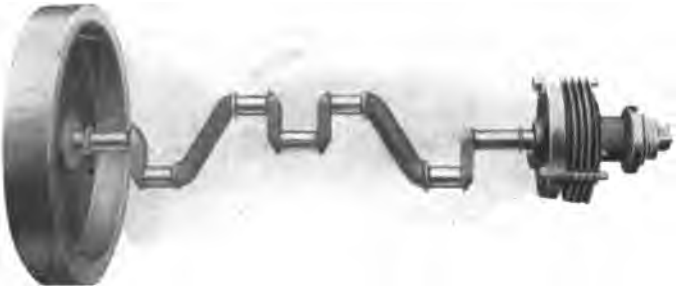


Fig. 35. Stevens-Duryea Fly Wheel, Crank Shaft and Disc Clutch.

The block chain adopted from bicycle service was the first form used on American motor vehicles, but being of bicycle size in almost every instance, was found totally inadequate and was therefore almost universally condemned. Not only the chain but the sprockets were too small, with the result that both wore out quickly and breakages were frequent. The block chain has less parts than the roller, has less joints to gather grit, is less noisy and, if of proper strength and properly fitted to the sprocket, runs with as little friction and transmits power with as great efficiency as any device yet offered. Few block chains are in use to-day, but of the few, the Duryea is noticeable because the blocks are bored transversely, so as to just intersect the rivet holes, and this transverse bore is filled with a felt pad, which absorbs oil and keeps the rivets properly lubricated. The value of oil upon any bearing is self-evident, and this arrangement not only insures oil in the proper place, but permits the outer surfaces of the chain being kept clean and practically free from grit, so that the rivets are not likely to wear in their bearings, nor do the teeth of the sprockets wear so rapidly as usual.

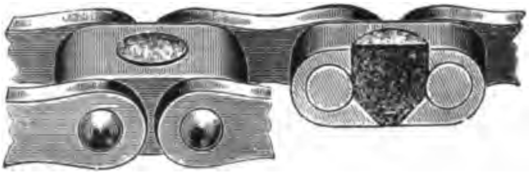


Fig. 36. Duryea Chain with Felt Lubricator.

The roller chain is the most common form and is so called because each rivet passes through a bushing around which bushing a roller is placed, so that the chain pull is taken by the roller bearing against the bushing, while the rivet is journaled inside the bushing. The reason for this is that as the chain lies down in its place upon the face of the wheel, the roller rolls down the teeth instead of sliding, but this reason is based upon chain imperfections and is not a proper one in connection with good chains and properly cut sprockets. If the chain and sprocket fit

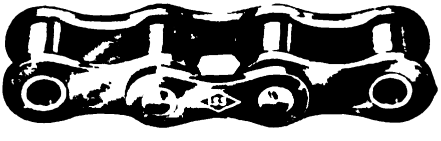


Fig. 37. Roller Chain.

properly, the pitch of the chain is slightly less than that of the sprocket, so that the rollers or blocks rise and fall out of and into their places, as the sprocket revolves, without friction. If, however, the chain is over-pitch, it will be loose at the middle of its length of contact on the sprocket and will grind and bind where it comes in contact and where it leaves the sprocket, and while rollers may partly overcome this grinding, the loss of power in any event, is decidedly objectionable, and such chains should not be continued in use.

It is to overcome this defect in driving chains that self-adjusting chains, like the Renold silent and the Morse silent chain, have been put upon the market. These have not come largely into use on autos because of their high first cost, but they are undoubtedly most meritorious, as they wear as long as gears, are more flexible, are less noisy, transmit as much power for a given width of tooth and need no more attention than gears. Their decided advantage is in the shape of the link, which causes the chain to select its own pitch line on the sprocket. Because of this feature they do not stretch and get out of pitch as do chains of ordinary construction, but any stretch of the chain, due to the wearing of the pivots, is compensated for by the fact that the chain automatically takes a larger pitch line position on the sprocket, whereas in chains of the usual kind an increase of pitch causes the chain to grind and rapidly wear the tooth surfaces, as the chain takes its position on the sprocket with much loss of power and with an increasingly rapid destruction of both sprocket teeth and chain.

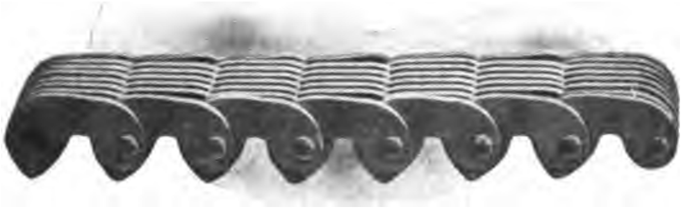


Fig. 38. Morse Silent Chain.

The pitch of a chain is the distance from center to center of similar rivets, having one chain link between them. In roller and the silent chains mentioned, it is the distance between rivets. In block chains each link is composed of one block and two side pieces, which are held together by a rivet, so that the pitch of the chain is the total of two spaces adjoining. This pitch distance is measured in a straight line forming one side of a polygon having as many sides as the sprocket has teeth, and corresponds to the older and now less used circular pitch as applied to spur gears. In circular pitch the gears were measured from center to center of tooth, just as sprockets are measured, these measurements being taken on the pitch line. In the later and more common method of measuring gears, the pitch is expressed by the diameter of the gear at the pitch line. Thus, an eight-pitch gear has eight teeth on its circumference for each inch of diameter. The pitch line of a gear is about midway of the tooth and is the line common to both gears; similarly the pitch line of the sprocket and chain is the line of the rivet centers as the chain lies upon the sprocket.

Although less applicable to belting, the pitch line of a belt is approximately at its center and should be taken into consideration when considering pulleys for belt driving.

In some vehicles more than one chain is used, either from the motor shaft to the counter shaft, as in the Holsman,—which employs chains for its change-speed device—or as in many forms of large vehicles which employ two chains from a counter shaft to the rear wheels. The counter shaft is parallel to the rear axle but in front of it, and is fitted with a sprocket on each end, in line with the large sprocket on the corresponding rear wheel. This construction is usually applied to heavy vehicles, and in this construction the balance gear is in the counter shaft and power is frequently transmitted from the change-speed gear to the balance gear by propeller shaft.

Chain troubles usually consist of broken links or sheared rivets, due quite frequently to something getting between the chain and sprocket and thus subjecting the chain to undue strain. If the chain is quite loose, it may climb on top the sprocket teeth with the same result. As the chain wears and increases its pitch length, the tendency to climb the teeth is increased and it will run with a grinding noise, indicating rapid wear. A block chain can usually be reversed with good results after it is partly worn. Extra links are usually carried for repair purposes, and some chains have their rivets buttonholed into the side links, while in others the rivets are held by cotter pins, so as to permit quick repairs to be made.

Chains have been condemned because they have been abused, whereas if properly designed, cased, and cared for, as is necessary with gears, they will give as good or better service.

The propeller-shaft transmitting device is so named because of its resemblance to the shaft used to transmit power from the motor to the screw propeller in boat service. At its forward end it is driven by the motor or change-speed gear just as in a launch, while at the rear end it is fitted with bevel gear usually of small diameter, meshing into a larger bevel gear on the rear axle or counter shaft at right angles to the propeller shaft. In some cases a worm gear is used instead of the bevel, while in others equivalents having pins and rollers instead of teeth are employed, the aim being to reduce the friction of the bevel gear. The bevel gears are commonly encased to hold oil and keep out the dirt, and this casing contributes very largely to the good service given by such gears. In all bevel gears there is a decided thrust against the bearings, which must be strongly resisted if the gears are not to become separated at their pitch line, causing increased noise and friction.

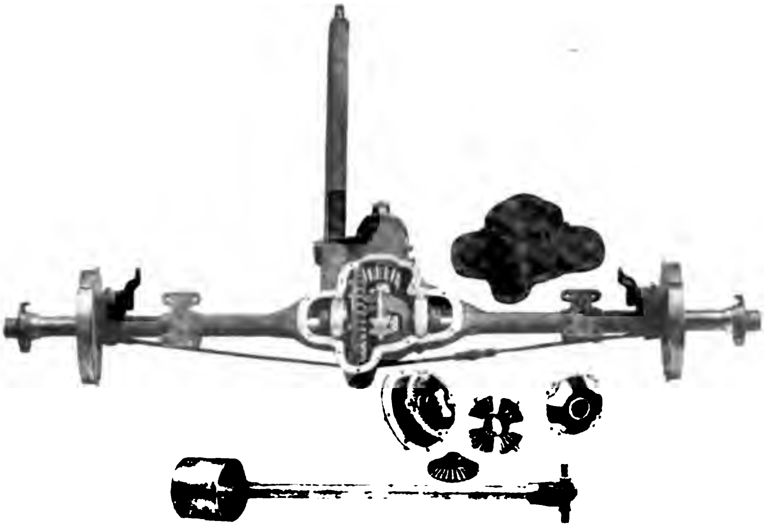


Fig. 39. Propeller Shaft Transmitting Device.

Gimbal Joints. Because of the impossibility of holding the motor at the front of the propeller shaft and the gears at the rear in alignment with each other, it is common to provide the propeller shaft with knuckles or gimbal joints, which, while transmitting power perfectly, permit the shaft to yield and change its direction ten or even twenty degrees. The propeller shaft is usually provided with a telescopic joint which permits it also to vary in length between ends, and these two accommodations allow the springs of the vehicle to perform their function without interfering with the transmission of the power. A great variety of gimbal joints have been employed and the same is true of the telescopic joint. These joints are frequently encased in leather cases packed with hard grease, which both keeps out the dust and insures lubrication.

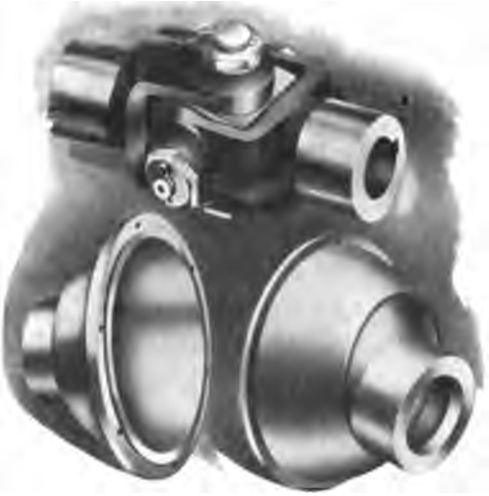


Fig. 40. Gimbal Joint.

Radius Rods. The propeller shaft is frequently paralleled by a torsion rod or bar having sufficient stiffness to resist the push of the bevel gear as it transmits the driving effort to the axle. In any event, this strain must be resisted by some means, and in connection with chains it is manifested as a forward pull parallel to the chain, which is taken by distance or radius rods arranged to extend from the driven axle to, or nearly to, the driving one. In some faulty constructions the distance rods are

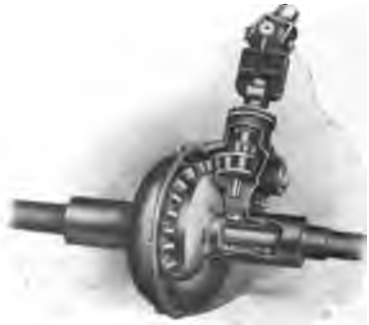


Fig. 41. Roller Bevel Gears and Universal Joint.

attached at one end or the other some distance away from the axle centers with the result that the spring action gives rise to a travel of the axle not coincident with an arc drawn around one axle center and passing through the other, and the result of this lack of proper movement is either to loosen the chain or tighten it, resulting frequently in the chain running off or being strained so forcibly as to break it.

Balance Gear. The balance gear, frequently called differential, or jack-in-the-box, is a device intended usually to transmit the power from the sprocket or bevel gear to each half of the countershaft or rear axle and thus to each wheel equally at all times, regardless of whether the wheels are turning at equal speed on a parallel course, or one slower than the other, as in turning a corner. In its simplest form it consists of two large bevel gears attached one to each half of the rear axle, which carries at its outer ends the driving wheels, or in the case of the countershaft, the sprockets for the side chain. Between these large bevel gears is journaled the driven sprocket or driven gear, the hubs of the bevel gears sometimes forming the journals. In this sprocket or gear are one or more pinions, usually three or four mounted substantially upon spokes and arranged to mesh into the large bevel gears of the balance gear.

In theory each of these pinions is simply a lever receiving the pull of the chain at its center and because its ends (opposite teeth of the pinion) engage the opposite bevels, it transmits half of the pull received to each of the bevels. When the vehicle runs on a straight course the pinions and bevels revolve as a solid mass without relative motion, but if, as in turning a corner, one bevel and its corresponding rear wheel takes a slower motion, that end of the lever (pinion tooth) is retarded, while the opposite end of the lever (pinion tooth) moves forward more rapidly, driving the outer wheel of the vehicle with increased speed. In all cases the amount of force applied to each wheel is the same, since both ends of the lever are of equal length, the only variation being a slight loss by friction, due to the motion of the parts of the gear in relation to each other. While the bevel gear is the simplest form, many balance gears are constructed by the use of spur gears because spur gears are manufactured more cheaply. In this form each half-axle is fitted with a spur gear, while the sprocket is provided with studs or bearings parallel to the axle on which are journaled long spur pinions, usually of small diameter. At their inner ends, these pinions mesh into each other, but one projects to one side of the sprocket, the other to the other side, and these projecting ends mesh into the spur gears. The power transmitted to the sprocket is, by the teeth of these pinions, transmitted equally to the spur gears in which they mesh, while variations in speed are met by the rotation of the pinions in opposite direction, which accomplishes the same result as the rotation of the bevel pinion.

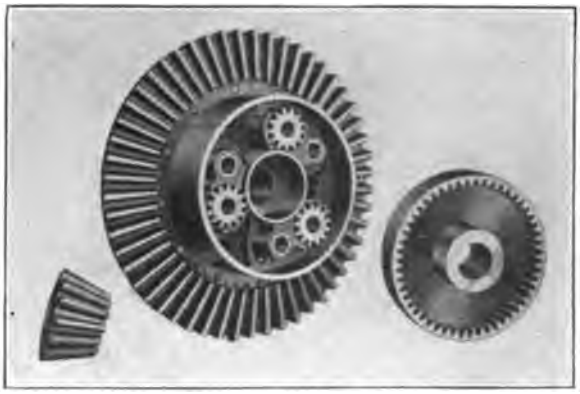
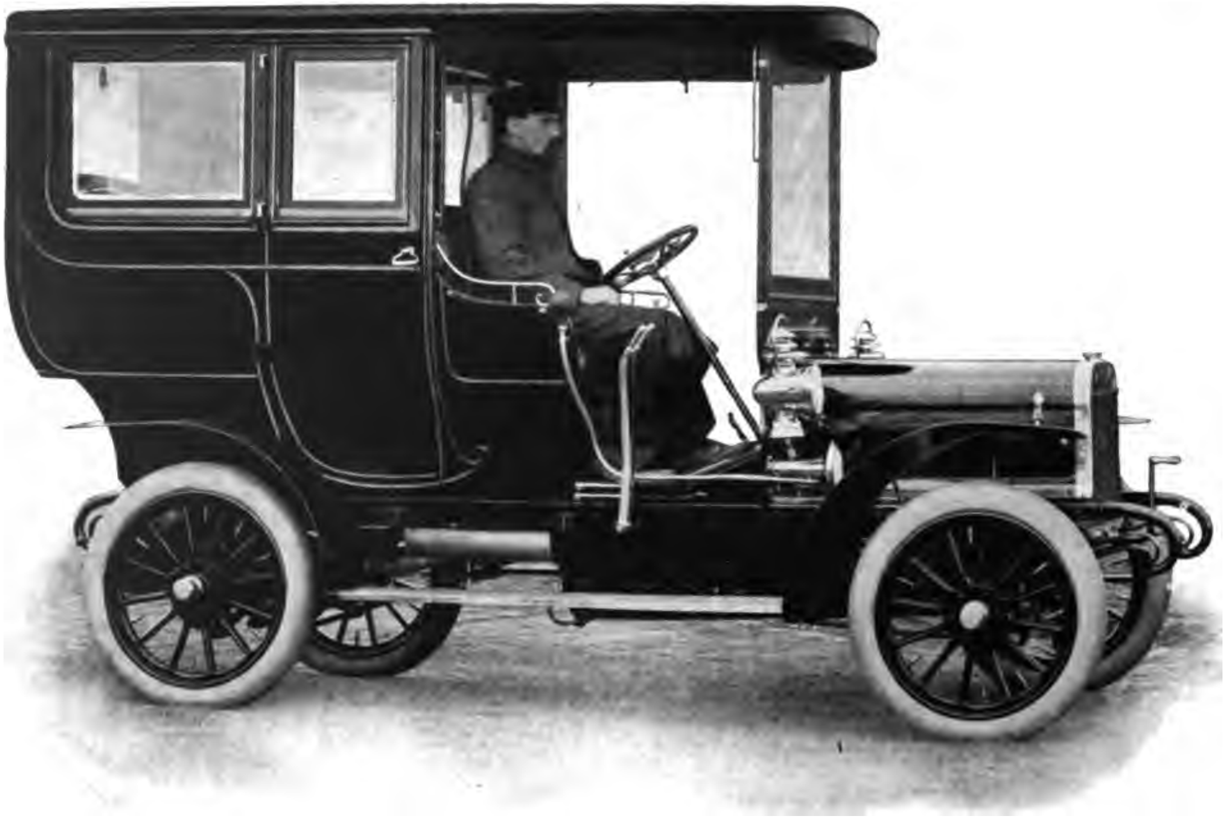


Fig. 42. Spur and Internal Balance Gear.

A third form of this device now little used, employed a spur gear on one half axle, an internal gear of larger diameter on the other half, with a single spur pinion meshing into both and mounted on a stud projecting from the sprocket. The pull of the sprocket was transmitted by this stud and pinion equally to the large internal gear and the small spur pinion, but since the point of application or pitch line of the internal gear was farther from the axle center than the pitch line of the spur gear, the effect was to drive the one wheel more strongly than the other. This arrangement is particularly advantageous where the resistance to be overcome is greater on one side of the vehicle than on the other, as for example in the three wheeler having the third wheel arranged to track with one of the drivers, for it differentiates or transmits the



LIMOUSINE TYPE OF AUTOMOBILE, 1906 MODEL
The Winton Motor Carriage Co.

power in different proportion, whereas the usual form being balanced, is really a balance gear.

Other devices are in use to transmit power to both wheels, as is necessary to secure traction and a forward movement without a tendency to shift to one side, and most of these aim to avoid the balance gear. The objection to the balance gear aside from its cost and weight is principally that if one wheel strikes a slippery spot, as a piece of ice, and slips backward, no power is transmitted to the other wheel and propulsion ceases. This is because the slipping wheel moves at double the angular velocity of the sprocket instead of at the same velocity as would be the case if both wheels were revolving at the same rate of speed.

In one or more types of friction-drive vehicles two driving discs are used and no balance gear is employed, it having been found that the friction discs will slip sufficiently to permit satisfactory turning, while on the other hand, if one vehicle wheel slips, the driving ability of the other is in no wise lessened. In the rope-driven Holsman, and one or more of its type, the slip of the driving ropes is utilized in a similar manner. The Hedgeland solid axle not only does away with the loss of strength or the increase of weight, due to the use of half axles, but it secures a positive drive to the slow wheel and thus avoids loss of traction by the slipping of one wheel. In this device each end of the axle is provided with a clutch fitted to the wheel hub so as to remain free when the wheel moves faster than the axle or when the axle stands still with reference to the frame of the vehicle. A forward movement of the axle causes the clutch to grip the wheel and drive it forward, but at all times

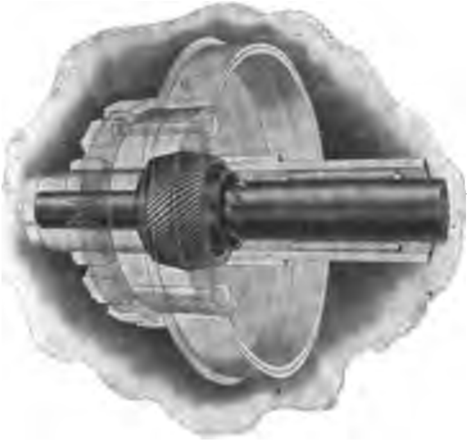


Fig. 43. Hedgeland Solid Axle.

the wheel is free to turn with greater angular velocity than the axle and thus releases itself.

In reversing, the same action results in the opposite face of the clutch being brought into service, while in coasting the vehicle runs free without the necessity of turning the rear axle and propelling mechanism.

Rear Axle. Directly connected with the balance gear is the design and construction of the rear axle. A quite common form consists of two half axles passing through the tubular half frames, which are bolted together around the balance gear forming the balance gear box, frame or spider. Each half axle is a duplicate of the other as is each half of the rear framework, and each is provided with bearings at the inner end near the balance gear and at the outer end adjoining the vehicle wheels. In some construction the balance gear is not exactly at the center but is at one side, making one of the rear axle parts and the tubular portion of its case shorter, while the opposite parts are correspondingly longer.

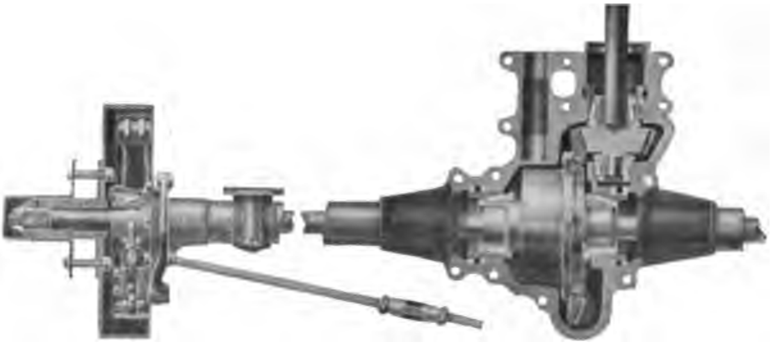


Fig. 44. Rear Vertical and Horizontal Views of Shaft-Driven Rear Axle.

A second form of axle employs a full length axle, having fixed, generally near one end, one of the balance gears, while slipped over this end, is a sleeve, carrying the other balance gear. The outer end of the sleeve on one side and the outer end of the axle on the other are fitted to the corresponding vehicle wheels. A nut on the sleeve end of the axle holds the sleeve in position, and sometimes also holds the wheel in place, the whole forming a simple and satisfactory construction. Both of these forms are what is known as "live axles," *i. e.*, axles which revolve with the wheels. They are advantageous in that the use of a single sprocket is permitted, and this may be placed in under the vehicle, thus bringing the chain away from the dirt of the wheels, where it is less unsightly and more durable. The disadvantage of the live axle is that it must be quite strong to properly carry a given load, because in revolving it is subjected to stresses in opposite directions, and is therefore likely to be broken.

Dead axles are commonly used on heavy vehicles, and these are substantially the same as on horse vehicles. With this construction each driving wheel is fitted with a sprocket from which a chain runs, usually forward, to the projecting end of the countershaft. The balance gear and axle constructions heretofore described, apply, with slight modifications, to the countershafts, which, because of the gear reduction between the countershaft and the rear wheels, need differ only in that they are not so strong and heavy.

Front Axle. The front axle of a motor vehicle differs usually from horse vehicle construction in that there is no fifth wheel at the center of the axle about which the axle turns for steering purposes, although this construction is sometimes used; but generally each end of the axle is provided with a steering head into which a vertical spindle or neck is journaled, which neck carries the axis of the corresponding front wheel. To this neck is attached one or more steering arms for controlling the direction of the neck; and that the opposite wheels may be steered in unison, an arm on one side is connected with a corresponding arm on the opposite side by a tie-bar parallel to the front axle.

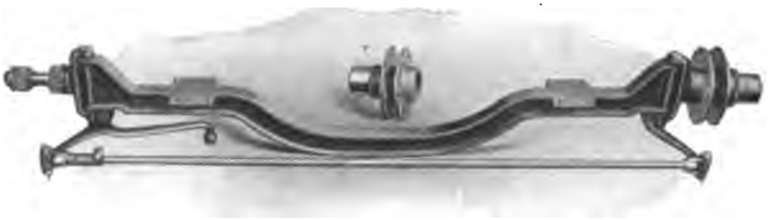


Fig. 45. Complete Front Axle Showing Steering Heads and Tie-Bar.

It is readily seen that in turning a corner both front wheels should be so turned that each will describe an arc concentric with the arc of the other, for if both arcs are not concentric, one wheel or other will be forced to slip sidewise to a greater or less extent, with the result that the tires will be worn and the steering will sometimes be controlled by one and sometimes by the other wheel, with consequent greater skidding and a very disconcerting eccentricity in the matter of steering. The same result is found in driving straight ahead if the steering wheels are not parallel to each other as they should be.

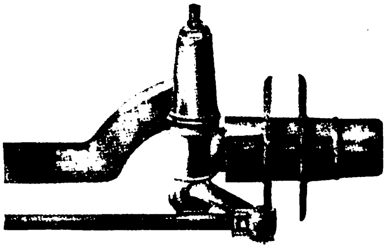


Fig. 46. Front Axle with Lemoine or L Head.

To insure that the steering wheels describe concentric arcs, the steering arms are projected either backward and inward from the steering neck or forward and outward, and the tie-bar is made of suitable length to hold the wheels parallel for straight ahead driving. This arrangement insures that the inner wheel on a turn will be steered at a greater angle from the center line of the vehicle than the outer wheel, and will describe an arc of a circle of shorter radius than the outer wheel. It is quite evident that both wheels should steer around a common center and that the radius for one wheel in one case must be the width of the vehicle, usually about 5 feet, greater than for the other wheel. The proper angle for these steering arms depends upon the distance between the axles and the distance between the steering head center lines, and is found approximately by drawing a line through the steering head center to the middle of the rear axle.

Steering Heads. Steering heads are of several varieties according to the ideas of the designer. The simplest form is an L-shaped forging welded to the end of the straight front axle, the other member of the L projecting upward or downward, and in either event bored to receive the steering spindle. This is quite frequently termed the Lemoine type. A second form provides the axle with a T head, the extremities of the T being turned at right angles, so as to form lugs through which the steering pivot pin passes. This also passes through the steering neck fitted between the lugs. This form is commonly termed the Elliott type. Recognizing the advantage of having the steering pivot as close to the spokes as possible, several makers made these projecting lugs very long, and in place of the vertical neck a curved C-shaped neck was provided carrying the spindle at its center, while at its ends short pivots or screws attached it to the lugs mentioned. This arrangement permits the use of a long wheel spindle and although slightly more expensive to build, and not quite so rigid as the other types, was used because of its merit by Haynes for a number of years.

In any steering device, the object is to have the steering pivot close to the wheel, so that the leverage of the wheel is extremely small, on which account obstacles do not have much tendency to deflect the course of the wheel. Any one who has watched the long pole of a horse wagon sway violently as the front wheels strike an obstacle, can realize how impossible it would be to control a motor vehicle by the arm of an operator unless a considerable mechanical advantage is gained in some manner, and placing the steering centers nearly or quite in the plane of the wheel, secures this advantage to a more or less complete extent.

Some vehicles are equipped with hubs of such size that the steering pivot may be placed exactly in the plane of the wheel, the wheel bearings being of larger diameter than the length of the steering pivot. Other vehicles use forks astride the wheel with the steering pivot over the wheel as in cycle construction. Both of these methods remove all leverage from the wheel, so that there is no tendency to deflect to one side or the other when it strikes an obstacle; but the large hub is objectionable and the long fork with the long framework necessary to get above the wheel is both costly and weak. The advantages of these constructions can practically be secured without additional cost or disadvantage by inclining the steering pivot so that the steering pivot center line strikes the ground at the same point as does the wheel. This construction is used on a number of vehicles at present and its merits will eventually force it to be used by all.

A few vehicles have been steered by the single kingbolt and fifth-wheel arrangement used on horse vehicles, in connection with a worm and segment for turning the axle about this pivot. This form is common in vehicles which both drive and steer by the front wheels, and is quite practical if means for steering by the power of the motor is provided. In order that the worm may have the power required it is of slow pitch and needs many revolutions to effect the desired steering, which rapid movement is not easily made by the operator. A device is easily provided, however, so that the motion of the motor drives the worm in either direction at will and accomplishes the desired result.

A double form mounts both front and rear axles on fifth wheels and swings them in opposite directions, thus steering both ends of the vehicle.

Front axles are usually solid, although sometimes made tubular for the purpose of saving weight. A single tie-bar between the steering arms is commonly used, but for the purposes of safety double ones are sometimes provided.

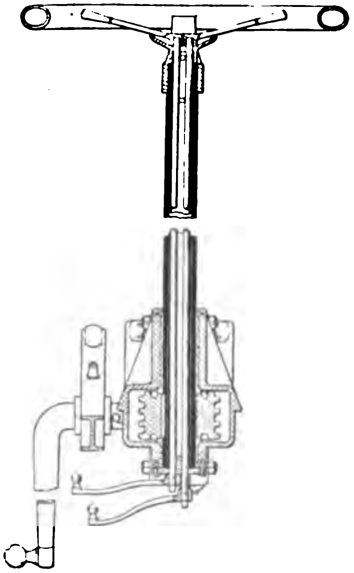


Fig. 47. Steering Wheel.

Control. In order that the front wheels may be controlled by the operator a number of means are used, the most common of which is known as wheel steering. This consists of a rotatable post fitted with a wheel at its top end and with a crank, pinion, or worm at its lower end. Where the crank is used a connecting rod connects the outer end of the crank with one of the steering arms which project from the steering head. Turning the wheel to one side a quarter turn throws the steering wheels to their limit in one direction from the center position, and a similar opposite turn throws them in the opposite direction. As commonly arranged, the post is turned in the same direction as are the steering necks, so that the rear of the steering wheel moves in the same direction as the rear of the front wheels of the vehicle. In the earlier forms the steering post was vertical, but it is now considered advisable to incline the post backward at the top so that the operator's seat need not be so nearly over the front axle. The front end of many vehicles is now utilized for the motor and as the wheels are steered, the front of the vehicle moves to one side or the other in a manner not found in horse vehicles and not conducive to comfortable riding. This objectionable feature is not found farther back, on which account the passengers are usually carried nearer to the rear axle. In some vehicles, the vertical post is equipped with a tiller or rearwardly projecting lever. This was formerly much

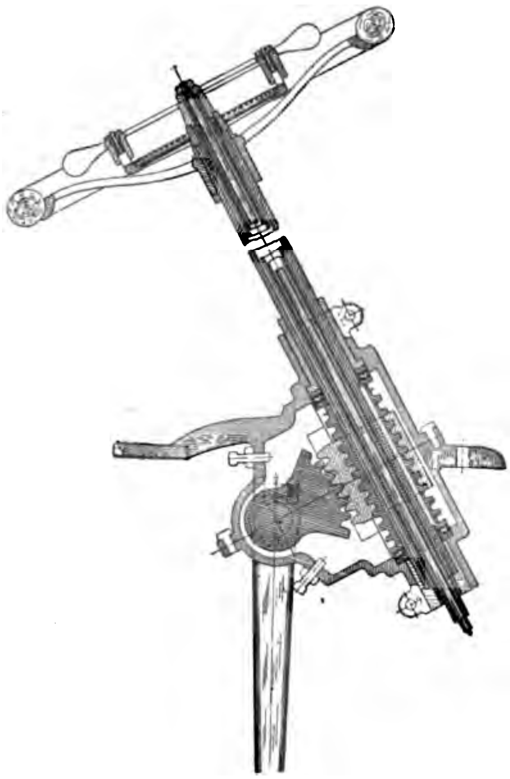


Fig. 48. Steering Wheel Showing Throttle and Spark Levers.

used on light vehicles and is a simple, natural method of steering, but not so satisfactory as other methods.

In other instances, the vertical post stands at the center of the operator's seat or at one side thereof, while the steering lever projects across the vehicle in front of the operator. This gives a powerful method of steering and is preferred by many to the tiller steering.

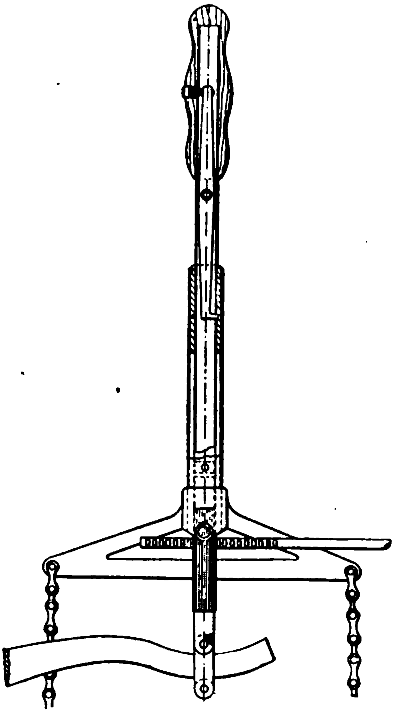


Fig. 49. Duryea Controlling Lever.

Swinging the lever sidewise pulls the chains and steers the wheel. Sliding the handle up or down shifts the lever setting either the high or low clutch. Twisting the handle shifts the rack which controls the throttle.

In order to get still greater power, double levers or handle bars have been used, but the preferred method is the wheel operated by both hands in connection with the worm or pinion at the bottom, by which arrangement the rotation of the post is not confined to a half revolution but is usually arranged to make nearly two revolutions and in some cases more, in order to turn the steering wheels through their extreme movement. It will be understood that the pinion meshes into a sliding rack attached to the proper end of the connecting rod, and that the amount of movement of the front wheels depends upon the diameter of the pinion.

When a worm is used the arrangement is slightly more complex, there being usually a segment of a gear adapted to mesh into the worm, so that a quarter revolution around the center of the gear is produced by the two or more turns of the steering post. Attached to this segment is an arm connected usually by ball and socket joint to the connecting rod. The advantage of this construction is that the worm locks the front wheels of the vehicle in position, against deflection by obstacles or causes other than the will of the operator. This arrangement is known as lock steering and is preferred by some. The free steering is the more common form, however.

A further form of steering employs a vertical lever carried by a horizontal pivot at the center of the seat near the front, and arranged to swing sidewise for steering purposes. This lever is between the passengers, does not interfere with mounting or dismounting, is in position to be operated by either passenger, and is much liked by those who have used it as well as other methods. Being patented, it is employed on one make of vehicles only.

Brakes. Second only to ability to go is the power to stop, on which account the brakes are most important. A wide variety of these have been used in the past but practically all have been abandoned excepting band brakes. A tire brake consisting of a shoe bearing against the tire of the wheel is considered detrimental to the tires and does not hold well on wet rubber. Band brakes are applied to the countershaft, to the rear sprocket, to the large gears of the balance gear and to the hubs of the wheels. They are of two varieties,—internal or expanding bands, and external or contracting bands. In the earlier form the external band was commonly used, one end being fixed to the frame of the vehicle, while the other was attached to the operating lever. Application brought the loose end in contact with the revolving drum which caused the band to tend to wind itself around the drum, forming a very effective brake without requiring a great amount of power for operation. This form was faulty when running backward because the friction of the loose end of the band against the drum tended to release the band, with the result that brakes of this kind hold well in one direction but not in the other.

Most forms of band brakes now are attached at the middle of the band, leaving both ends for operation. This insures that no matter which way the vehicle is moving, the brake is equally powerful. In one or more forms the band is provided with two points of support, one of which takes the strain in a forward direction, the other in a reverse; and since both ends are equally operated upon, this form of brake is particularly powerful and requires but the slightest effort on the part of the operator, being practically self applying. On the heavier vehicles internal and external bands are sometimes applied to the same drum affixed to the hubs. This utilizes double the surface and gives enormous braking power. Many varieties of arrangement are found, but the general principle is the same. Brakes are usually operated by foot levers, but many vehicles have also a hand lever.

Two methods of braking are considered good practice, and most vehicles can be stopped by throttling the engine or applying the proper clutch, so that even if only one brake is used, a second means of control is always present. Some makers believe it is better to fit one brake only, in order that the user, by using it daily, may not only know its condition, but may be trained to use it instantly and automatically, because it has been found that in emergencies the operator forgets special features like an emergency brake, and fails to use them even though he had depended upon them to the neglect of the condition of the more commonly used brake.

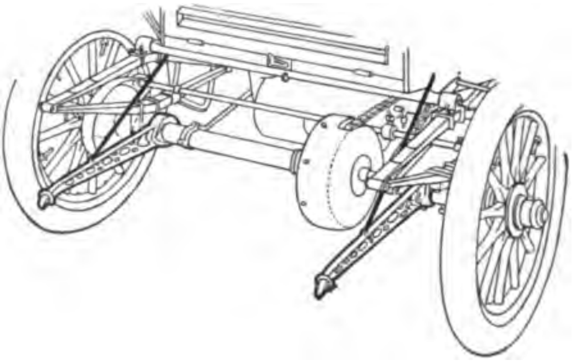


Fig. 50. Drop Brake.

To prevent movement backward in case of failure of the brakes, a sprag is commonly used. This is hinged to the rear axle of the vehicle and is let down at the bottom of the hill so that it drags, forming a pawl, which at the first backward movement of the vehicle digs into the ground, effectually stopping movement backward. Some vehicles have the wheels provided with ratchet teeth and a pawl to engage them in the same manner. Others depend on brakes only, but in order that the vehicle may be left standing on a hill, provide the brake levers with ratchet and pawl to hold them when set.

WHEELS

There are few more important parts in a motor vehicle than the wheels. These are sometimes made of steel, much like bicycle wheels, but the earlier forms were made too light, on which account this style of wheel has been largely condemned. The same fact applies to wooden wheels as commonly used on carriages, with the result that the accepted form to-day is the artillery wheel, a construction having wooden felly and wooden spokes with large butts. These butts join each other forming a complete circle of wood at the hub and are gripped between flanges of metal bolted together through the wood. Any loosening of the spokes at the hub is taken up by tightening the bolts. To the wooden felly is attached the metal rim which engages the pneumatic or solid rubber tire. Some wheels are in use having steel spokes and some experiments have been made with springs instead of spokes in the attempt to gain elasticity in the wheel instead of at the tire. The common wheel, however, is the artillery form described.

It is a noticeable feature of motor vehicle wheels that they are much smaller than the wheels of horse vehicles, although the loads carried are decidedly larger. The reason for this is three-fold. Pneumatic tires are costly, so the vehicle maker to save first cost, uses a small wheel with consequently small and cheap tires, and the buyer having no experience assumes that this must be best, after which the maker excuses himself by saying: "The public wants it." Small wheels are doubtless responsible largely for the great tire and mechanical repairs frequently connected with motor vehicles, and also with the lack of practicability on bad roads, in deep snow, and similar conditions, successfully negotiated by horse vehicles. The second reason for small wheels is the fact that the motor runs more rapidly than the wheels, which necessitates gearing, and large wheels require a greater difference in gear ratios than do small ones, thus increasing the difficulty of the builder. A third reason for small wheels is their greater strength, but it seems wiser to use large wheels and decrease the weight of the parts to be carried, particularly over the rough roads found in most parts of America.

Tires. Since motor vehicles depend upon the wheels for propulsion, tires having great traction are necessary, particularly if a large proportion of the load is carried on the front wheels, which must be pushed by the rear ones. On this account rubber tires are practically necessary, because steel tires slip on every bit of ice, on iron rails, and even on hard pavements unless caused to grip by spikes or similar projections, which are both rough and noisy. On some vehicles blocks of wood, presenting the end of the grain to the street, are used instead of tires and are found more durable and less expensive than rubber and less noisy than metal, while giving good traction. For trucks, such tires seem well adapted. Wide heavy tires of solid rubber are also used on heavy vehicles, but the pneumatic tire from 2½ to 5 inches in diameter is the prevailing form. These not only give traction but smooth the road very perceptibly, and are therefore well adapted to high speed. Although many other styles are constantly being tried, such as various forms of arched or cushioned tires, also tires having steel springs for resiliency, the pneumatic tire is almost universal.

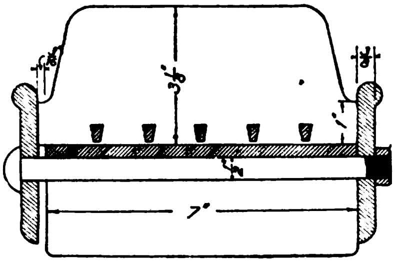


Fig. 51. Solid Rubber Tire for Heavy Vehicle.

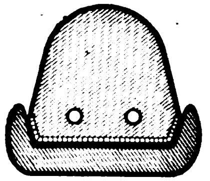


Fig. 52. Solid Rubber Tire for Light Vehicle.

This was formerly most common in the single tube shape, but of later years the detachable tire, consisting of an outer shoe or casing with a removable air tube, has become the favorite. Metal rims are nowadays provided with one side removable, which permits the tire to slip off easily, after which the air tube can be repaired or a patch laid on the inner side of the casing. Three common forms of tires are in use at present.

The Clincher tire is so called because as first constructed, its edges were provided with hooks or clinchers, which engaged similar hooks along the edge of the rim. As now constructed these are practically abutments resting against the upturned edges of the rim, the tire being held down in the rim by its constrictive fabric, which causes it when inflated to shorten in length and grip the rim forcibly. Clincher tires are sometimes held in place more positively by large-headed bolts, which clamp the edges of the casing between the heads and the sides of the rim and prevent the tire from lifting and blowing out of the rim when turning corners at speed, or when partly deflated.

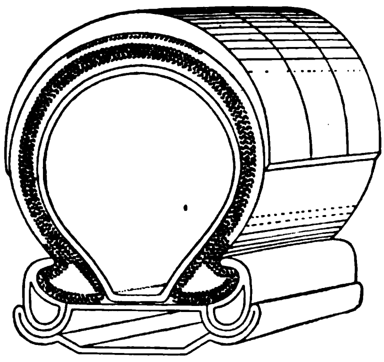


Fig. 53. Clincher Tire.

The wired tire has an endless wire fitted in each edge. This wire is just large enough to pass over the base of the rim and cannot pass over the flange or side when in place. In this form the wire performs the duty of holding the tire to the rim, so that the fabric is called upon only to retain the air pressure within the tire and may therefore be less strained than in the constrictive form where it must both hold the air and also the tire itself, thus performing a double duty. A third form has its edges clamped along the sides of the rim by mechanical means. This is a most positive fastening, effectually preventing creeping, rolling, or blowing off, but it is not so quickly removed for repairs as is the wired tire with removable flange to the rim.

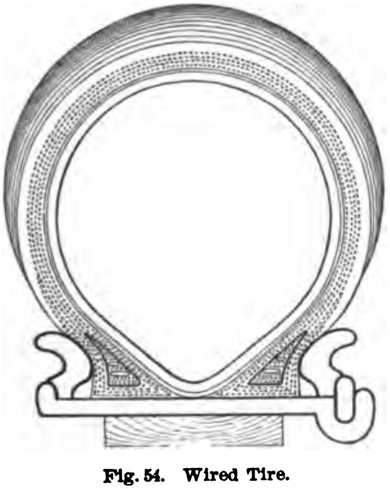


Fig. 54. Wired Tire.

When deflated the removable ring is pushed inward, the bead removed from its groove, after which the removable ring and tire slip off freely.

With tires as with wheels, the size is important. The strength of rubber and fabric is quite limited and a surface sufficiently large to support the load without damage to the rubber, must be provided if the tire is to be durable. The constant bending of the tire in the performance of its duty, wears out both fabric and rubber resulting in bursts and blow-outs, while danger of puncture is always present. These objections are best overcome by the use of tires of small diameter in cross section on wheels of large diameter. In this form the contact on the ground is quite long, thus securing a large supporting surface; the wheel revolves less times per mile, thus bending the tire less often, as well as allowing the heat caused by the bending of the tire to dissipate; and finally, the narrow tire is less likely to puncture, for it does not pass over so wide an area and therefore encounters proportionately a less number of causes of puncture. Further, it meets less resistance from mud, sand and gravel, skids less, and therefore is less damaged than a tire which slips and skids more frequently, because it is abuse rather than use which damages any construction. The tire of large section on a small wheel has a bearing more nearly circular on the ground and slides like a snow shoe easily in any direction and thus contributes to skidding, whereas the large wheel with narrow tire is more like a sleigh runner and less likely to skid sidewise. The large wheel rolls out of depressions easily instead of slipping around in them, and it is believed by many that skidding and rapid wear are largely found under the same conditions.

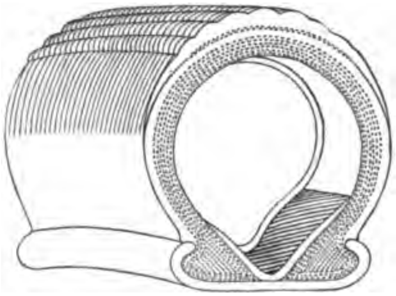


Fig. 55. "G. & J." Tire.

A sudden application of the brake will frequently start skidding, and this is known to conduce to tire destruction. The same remark applies to sudden or jerky applications of the power. On this account the operator should cultivate handling the vehicle smoothly without jerks or abuse. In case of skidding, minimize the trouble by easing the brake or partly shutting off the power, and at the same time swinging the steering wheels, so as to carry the front end to the same side as the rear. Jamming on the brake or shutting off the power suddenly is liable to make the matter worse.

IGNITION.

One of the most important features of the gas engine is the ignition. It is also the most delicate, and therefore the first place to look for trouble when things go wrong. Present day autos make use of one of three systems of ignition and some are fitted with two forms so as to have reserve if one form fails. In America the make and break spark was the earliest form and has been continued by one maker until the present. This form, also called the wipe, touch, contact or kiss spark, employs two electrodes within the cylinder, one of which is usually insulated in a fixed position, while the other is not insulated, but is movable and arranged to come in contact with the fixed electrode and be separated at the moment the spark is required. In some cases the movable electrode is insulated instead, and in still other cases both electrodes are insulated.

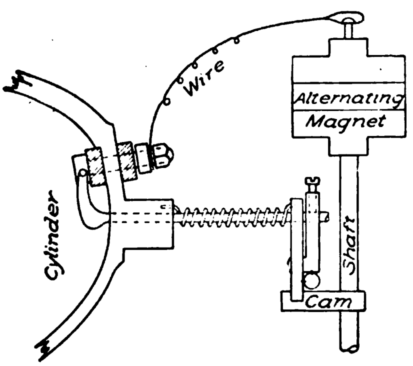


Fig. 56. Make and Break Ignition.

The electric circuit from a battery or other source passes directly through these electrodes, but in order that the spark may be rendered more intense than would otherwise result, it is customary to introduce a simple coil into the circuit, except in such cases as do not need this because of the nature of the generator. The low tension alternating magneto, for example. needs no coil, the windings and core of the armature serving this purpose perfectly. A shunt-wound dynamo will also give a large spark without the use of a coil if the contact is but instantaneous. The coil used with a half dozen cells or with direct-current magnetos or dynamos is identical with that used for lighting gas in dwellings. It consists of a core of soft iron wire, 5 to 8 inches long by about 1 inch in diameter, wrapped with four to ten layers of insulated copper wire $\frac{1}{16}$ inch diameter. When a current passes through this coil, the core is saturated with magnetism, thus storing, as it were, the energy of the current. When the circuit is broken at the electrodes by separating them, the magnetism in discharging from the core induces a very intense current in the coil, which jumps the gap between the electrodes, making a spark so intensely hot that even heavy cylinder oil is vaporized and any reasonably explosive mixture is ignited with certainty.

The movable electrode is operated by any suitable mechanism, which differs in different designs, but it is a common practice to bring the points together by a strong spring and to separate them by a blow as from a hammer. The coil used must both charge and discharge quickly in order to be suited to high speed work, and since the spark is caused by the discharge, the points must be separated far enough (nearly $\frac{1}{8}$ inch), to give ample room for the spark before the strength of the discharge has been spent, so that in this, as in the vibrator of the ordinary jump spark coil, a sharp, quick break is an essential feature. The moving parts must also be light in order that they may move quickly. The merits of this system have compelled recognition from the best makers and it now seems likely to supersede the jump spark on high grade vehicles.

In France the jump spark was used as early as 1862 by Lenoir, and later by Benz in Germany. It was brought to its most successful form on high speed motors by DeDion and Bouton about 1896 and its success on the many little tricycles turned out by this concern gave it an impetus into public favor, which it has largely since retained. In this system the two electrodes are both fixed, generally in the form of a plug which may be screwed into the wall of the cylinder. Usually one electrode only is insulated, but both are insulated in some cases and connected to the two high tension terminals of the jump spark coil or transformer. This coil is quite complicated and consists of a primary winding, forming part of a primary circuit—the equivalent of the circuit employed on the make and break system—a condenser connected across the primary circuit on opposite sides of the circuit breaker, and a secondary coil

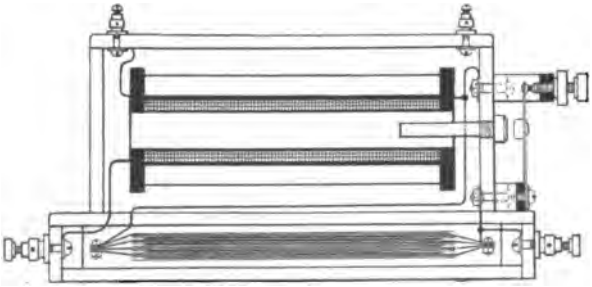


Fig. 57. Section of Jump-Spark Coil.

parallel to the primary, but much longer and of finer wire. The theory of this coil is that when a current is passed through a wire it will induce a current in another wire parallel to the first. When the circuit is broken, the core of the coil being saturated and discharging, as in the primary coil, induces a very strong electric impulse in the long secondary coil, with the result that a spark will jump a considerable gap between the electrodes to which the terminals of the secondary coil are connected. Because of this ability to jump, the system takes its name. In the primary circuit of both systems, the induced current tends to jump where the circuit is broken, but in the secondary circuit the induced current must jump the permanent gap because the terminals do not move.

In order to avoid the large spark at the breaker or vibrator in the primary circuit, a condenser consisting of many layers of tin foil insulated from each other by waxed paper, is arranged with alternate sheets connected to the terminals of the primary circuit on opposite sides of the circuit breaker. This device in effect prevents the discharge of the core from expending itself by producing a current in the primary circuit, and therefore increases or condenses the spark in the secondary circuit.

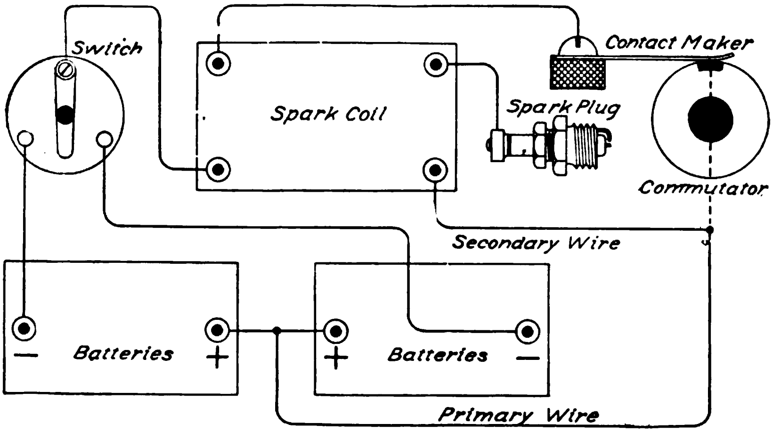


Fig. 58. Wiring Diagram of Jump-Spark Ignition.

In the simplest forms of jump spark ignition, the primary circuit breaker is operated by the mechanism of the engine, which causes the primary circuit to be broken when the spark is desired, just as in the make and break system. Since, however, better results are obtained by closing and breaking this circuit at a certain rate of speed, than at other rates, it is now most common to employ vibrator coils which have a spring arranged to close the circuit and employ the magnetism of the coil to attract the spring, when the core is saturated, and thus automatically break the circuit, resulting in a continuous vibration or buzzing with an accompanying stream of sparks. With this arrangement it is necessary to break the primary circuit in order to stop the sparks when not wanted, and to this end a timer is operated by the engine instead of the mechanical breaker. By means of this timer the current is connected at the proper time and the vibrator produces one or more sparks, one only at high speeds and several at very low speeds, as when starting. This timer is usually adjustable so that the circuit may be connected earlier or later as compared with the movement of the engine by which arrangement it is possible to produce the spark as desired, either after the piston has passed the dead center, or more or less before the dead center, in some cases 45 degrees ahead.

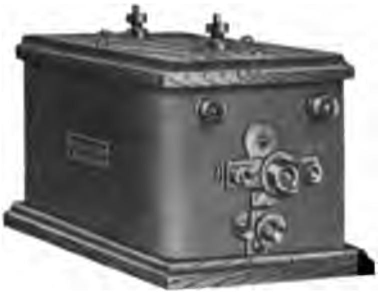


Fig. 59. Jump-Spark Coil.

The object of this advancement is two-fold. The jump spark is so small that the ignition of the explosive charge begins slowly. Second, the time required by the vibrator after the primary circuit is connected, is dependent upon the adjustment of the vibrator but may be such part of a second (usually .004 to .005) that the crank shaft will have moved 5, 10 or even more degrees of angularity before the spark takes place. This lag is particularly noticeable when the vibrator has just broken connection as the timer made connection, the result being that the spark cannot occur until the vibrator spring has made one movement and swung back into contact long enough to charge the coil.

This condition frequently exists with the result that ignition takes place at various times instead of at a fixed point, as with the make and break, and the position of the timer does not represent the average ignition position but rather the advanced position with average cases much behind and extreme cases still more so. Recognizing this effect, jump spark users are, to some extent, employing a single coil on multiple cylinder engines and distributing the secondary spark from one plug to the next by a well insulated commutator or distributor, so that the average position of ignition may be the same on all cylinders. If separate coils with separate vibrators are used, the difference in the vibrators causes a different average position of ignition and since the multiple point timer cannot be adjusted for one cylinder independent of another, the result is a slight difference in the strength of operation of the different cylinders.

Since the secondary or high tension current of the jump spark system is of sufficiently high voltage (10,000 to 25,000) to jump the gap between the electrodes while the charge is under compression, it will jump a very large gap in the open air, and must therefore be very carefully insulated. Rubber covered wire ½ inch or more in diameter is commonly used, the wire itself being very small. The plugs are usually of glazed porcelain or of tightly rolled mica or in some instances, of lava or other heat resisting materials. The gap between the electrodes or spark points is usually $\frac{1}{32}$ inch, or slightly more, and a spark to successfully ignite, under the influence of the resistance of the compressed charge, should have sufficient energy to jump ⅜ or ½ inch in the open air. A leakage of electricity from the high tension circuit can usually be seen in the dark by a slightly luminous brush-like discharge, and indicates a point where the insulation should be improved if the best results are desired.

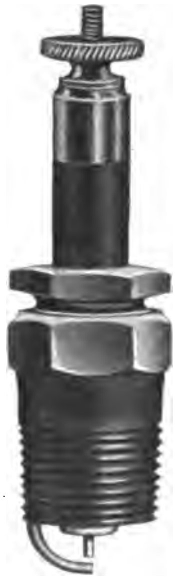


Fig. 60.
Jump Spark Plug.

A third system, which has attained some prominence recently, is the magnetic make and break, commonly called the magnetic plug. In this device the magnetism of the primary coil or of an auxiliary primary coil is used to separate the movable electrode from the fixed electrode instead of the separation being made by mechanical means. A timer is necessary in the circuit for the circuit is commonly closed and must be broken by the timer to prevent a continuous succession of sparks. The fault of this device is that it is not well adapted to currents of varying strength, as for example, the current from a generator driven by the engine; because in starting, the engine cannot be turned fast enough to produce a strong current and the magnetic plug will not operate, or if adjusted to operate on a weak current, it operates continuously on a small saturation of its magnet and breaks the circuit before the core is properly saturated as is required for large spark. To overcome these defects, a two circuit device has been used, both primary, and not complicated. One circuit operates the make and break while the other is a sparking circuit pure and simple. The magnetic plug is believed to combine to a large degree, the good features of both the make and break and jump systems and with suitable development will doubtless have a large future.

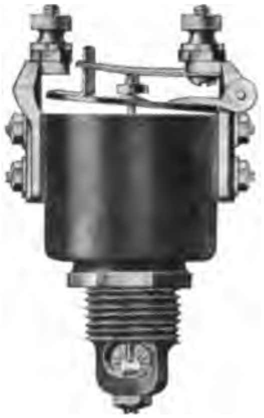


Fig. 61. Magnetic Spark Plug.

The hot tube ignition used by Daimler and others until the beginning of this century is now seldom found.

Galvanic Cells. The earliest source of current was galvanic cells employing a liquid electrolyte. These were sloppy, short lived and very unpleasant to handle, because of the nature of the electrolyte, which was either sulphuric acid, caustic soda, sal ammoniac, or something of this nature. Such batteries have been replaced by dry cells packed solid and simply moistened with a sal ammoniac solution. These are not likely to leak even when placed on their sides because of the small proportion of liquid contained by them. They are cheap in price and because of their use in telephone service, are purchasable almost everywhere. They deliver their output under a tension of one to one and one-half volts and therefore require a less number in series than most wet cells. The ordinary make and break coil is designed to operate with from 6 to 10 volts and 2 or more amperes, although very satisfactory results can be obtained with much less. The jump coil is usually wound for four to eight volts and gives best results if the amperage is quite large. Four to six cells in series is the customary battery, and good practice makes use of two or more series alternately until all are perceptibly weakened, after which two series are connected in parallel or multiple which doubles the strength (amperage), while maintaining the proper voltage. As the voltage of the cells decreases, connecting an additional cell in series is advisable.

Some users prefer storage cells known as accumulators or secondary batteries. These cells deliver two volts each, and since the internal resistance is low, they will deliver a large quantity of current and thus make a strong spark. They are prepared in small sets suitable for ignition purposes, giving four to ten volts, and although heavy, are quite reliable. Their first cost is greater than dry cells and the cost of recharging is frequently as much as a new set of dry cells. They are probably most satisfactory when used in connection with a direct current magneto or dynamo, by which they are kept fully charged and able to give a strong spark.

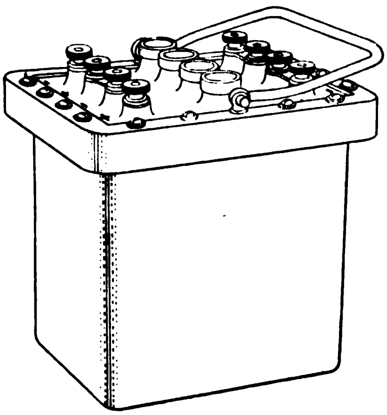


Fig. 62. Accumulator for Gas Engine Ignition.

Mechanical Generators. An early form of mechanical generator was a small shunt-wound dynamo. These are used to a considerable extent and not only give large sparks for both the jump and make and break systems, but also serve to charge batteries, light electric lamps, operate magnetic clutches and even operate magnetic horns.

The most common form of mechanical generator is the direct-current magneto, which differs from the dynamo in that the field is composed of permanent magnets. These generate current at lower speeds than the dynamo and the current does not increase in quantity with the speed to so large an extent, on which account it is better adapted to the varying conditions of auto work.

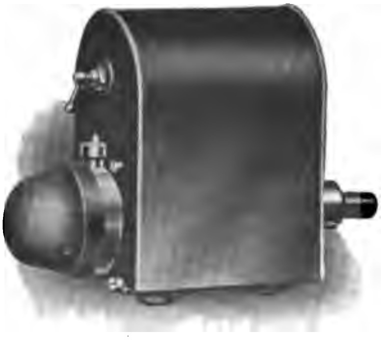


Fig. 63. Alternating-Current Magneto.

It is customary to drive these direct-current generators by friction pulley in contact with the fly-wheel, and some form of governor is provided to withdraw the pulley from contact and thus prevent the generator being driven at excessive speeds, and yet be driven by the small pulley at a speed fast enough to spark when the engine is running slowly. It is quite common to use these devices for starting the engine, but in many cases a battery of dry cells is provided which makes starting somewhat easier.

The alternating magneto will produce two sparks or electrical impulses at each revolution of the armature, and in order that these may occur at the proper time, it is positively driven by gears. This form has no brushes and only one contact from which the live wire is carried. The discharge of the armature serves the same purpose as a spark coil, so no spark coil need be used. As ordinarily made, these are about twice as heavy as the direct-current magneto and will give a spark at as low as 50 or 75 revolutions per minute, whereas the direct-current magneto requires five times this speed to generate a spark sufficiently strong for ignition. Of course, neither magneto will spark properly at such speeds, the alternator usually requiring several hundred revolutions, while the direct-current device or the dynamo are usually driven above 1000.

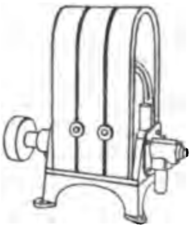


Fig. 64. Direct-Current Magneto

In case of trouble the brushes or contact points are usually at fault. The contact surfaces will frequently be found dirty and glazed in a manner to prevent the passage of current. Sometimes a bit of iron attracted by the magnetism forms a short circuit across some insulated parts. The bearings should be carefully watched, for if much worn the armature will strike and reduce the speed, or if dry, the friction of the bearings will be greater than that of the driving pulley and the speed will be too low for regular ignition. If the pulley surface is dry, apply belt dressing or a trace of heavy oil; but if greasy, apply powdered common chalk. Resin is sometimes used, but if the fly-wheel surface is hot it is not satisfactory, because it is oily when hot and increases the slipping. These remarks also apply to friction driving gears.

PUMPS.

Pumps are usually one of three varieties, centrifugal, vane, or gear, although reciprocating plunger pumps are occasionally used.

The centrifugal pump is usually 5 or 6 inches in diameter by 1 inch thick, with a revolving vane driven by a shaft which projects through a stuffing box forming one end of the axis of the pump. The water is admitted at a central opening on the opposite side of the case and leaves the case through a tangential opening on the edge. These pumps are not easily clogged, have no parts to wear or be noisy, employ no valves, and do not impede the natural circulation of the water if for any reason they cease running. They are quite usually driven by friction pulley and are generally speeded to 300 revolutions per minute or faster.

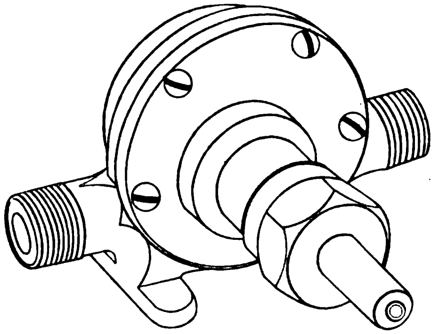


Fig. 65. Vane Pump.

The vane pump is somewhat smaller in diameter but of greater thickness and has the casing eccentric with respect to the shaft. The inner end of the shaft is enlarged concentrically to meet the closest inner surface of the casing, and a slide or vane is forced by the revolution of the shaft alternately back and forth through this enlarged end. This slide is frequently divided at its center and fitted with a spring, which keeps the ends in contact with the inner circumference of the case at all times. The inlet and outlet are tangentially placed on either side the contact point of the enlarged shaft end. The vane ends wear rapidly if the water contains grit, and small obstacles are likely to do damage. This form of pump is usually driven by gears or attached directly to the cam shaft or similar part of the motor.

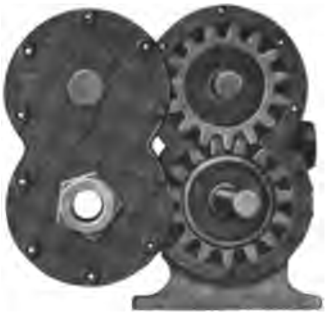


Fig. 66. Gear Pump.

The gear pump consists of two gears of coarse pitch, meshing together and revolving in a figure -8- shaped case, the inlet being on one side of the center, the outlet on the other. The liquid is carried by the tooth spaces around the ends of the 8 but cannot return between the gears because crowded out of the spaces by the meshing of the teeth. This pump has no valves but like the vane pump, is liable to damage if foreign matter is permitted to enter, and it is of small capacity in proportion to its size. These pump shafts are fitted with stuffing boxes to prevent leakage of water around the shaft. Prepared packings are usually supplied for these boxes, but candle wick filled with tallow or other heavy grease is quite commonly used.

Reciprocating pumps employing piston and check valves are sometimes used but not frequently, although common in launches.

Failure of the pump to work is usually manifested by rapid boiling of the water, smoking of the lubricating oil, and in extreme cases, by loss of power, premature ignition, with pounding, and the symptom of stiffness in the engine when turned by the starting crank. An air or steam trap or pocket is often responsible. Drain the system and refill taking care to get out all air. If clogged by solid material the pump must be opened although turning backwards may relieve it temporarily.

AIR FANS.

For air circulation the ordinary screw-blade fan is most common. This is seldom constructed with less than four blades and generally, in order that it may not be of great thickness in proportion to its diameter, it has eight to twelve or even more blades. It is usually mounted on ball bearings commonly run by V or round belts, although flat belts and spur gears are sometimes used.

Next in frequency of use is the practice of making the spokes of the fly-wheel serve as fan blades and thus avoid the fan with its extra parts, high speed, added bearings and extra oil cups. The use of a centrifugal fan or blower has been attended with good results and is advisable where much pressure is preferred rather than large volume of air. In some instances the energy of the exhaust has been used to induce a current of air and cause this to assist the cooling without additional mechanical parts.

Both pump and fan troubles usually arise from failure to be driven, generally because of slipping of the belt or friction pulley, or because some obstacle impedes the movement of the pump or fan. Pumps sometimes cease to work because they fill with steam, which leaks back through the pump as fast as it is forced forward. The remedy is usually obvious and the trouble is noticed when symptoms of overheating in the engine appear.

BODIES.

The bodies of most autos have one common feature, i. e., the operator's seat. This was formerly placed well to the front, as in horse vehicles, but because of the sudden sidewise movement of the front end, due to steering, this seat was found more comfortable if placed further to the rear, and since many owners are also drivers of their own vehicles, the operator's seat is usually at mid-length of the vehicle. The motor, originally under the floor of the vehicle, is now quite commonly placed vertically in front and covered with a bonnet, which utilizes the available space in front of the operator. On this account additional seating room is secured at the rear, over and frequently behind the rear axle. In some vehicles, as in the Orient, and Adams-Farwell, the motor is at the extreme rear, near the rear axle, while the passengers are carried between the wheels as in the horse vehicle ; a sensible and practical arrangment.

The form of additional seats has been a matter of wide difference of opinion. Some early vehicles had a front seat facing rearward. Later the dos-a-dos was considerably used because it permitted an unbroken space, under both seats, for the mechanism. The dust and exhaust gases behind the vehicle would arise unpleasantly in the faces of the passengers and this rendered such seats unpopular. Rear seats oppositely facing were next tried and this form gave way to the "tonneau," having a seat on each rear corner much resembling two water barrels, from whence the name. A door between these seats, opening at the rear, completed this form, but the necessity of dismounting in the street when the vehicle stood alongside the curb, soon destroyed its popularity.

Side door rears with an occasionally a side door front now prevail. This is a much nearer approach to the common horse surrey, and it seems likely that the satisfaction found by horse users will be accepted by auto users and doors done away with except in the heavier and more elaborate vehicles.

Emergency Seats. For temporary increased seating capacity, emergency seats are quite common. The high cost of the auto as compared with horse vehicles makes it necessary that one vehicle should serve several purposes instead of there being provided a variety of vehicles. When the mechamism was carried at the rear, a front seat usually facing forward and arranged with folding foot board and back was quite common, This was directly over the front axle, rode unpleasantly, required lap robs to protect ladies' and children's skirts from the wind, and exposed the passengers to dangers of collision and scary horses, as well as getting them in the way of the operator's vision. Seats facing the rear are still used in large tonneaus and serve well.

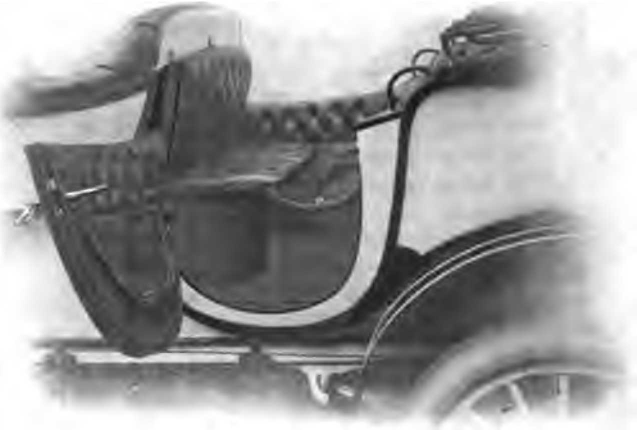


Fig. 67. Arrangement of Extra Seat.

The folding rear has been recently introduced and converts the runabout into a surry in a practical, comfortable and inexpensive manner. Unlike a detachable tonneau, it is always present when wanted, and quickly closed when not wanted. It adds little extra weight, requires no mechanical work to open or close and bids fair to be a permanent device.

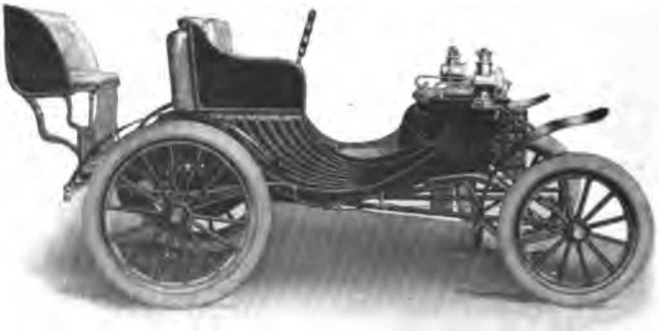


Fig. 68. Folding Rear Seat Phaeton.

In some forms of vehicles notably cabs and broughams, intended to be driven by drivers for hire, the operator's seat is at the extreme front or at the extreme rear as in similar horse vehicles. It seems evident that similar requirements will largely dictate similar forms in autos as in horse vehicles, and mechanics will doubtless be able to accommodate the mechanism to the bodies without great deviation from those vehicle forms proved by years best suited to the needs of the public.

Tops. Auto tops are substantially the equivalent of those used on horse vehicles although generally larger and more strongly made. They are either single or double, of the folding or cape top variety, with occasionally a canopy top and quite frequently a standing top with curtains or with glass windows, forming a completely enclosed vehicle. High speeds in cold weather have made some form of protection desirable, so glass plates are fitted in front of the driver and are used either with or without the top as desired. They should be folding or removable because the air carried behind them is dust laden in dry weather and in rain or snow one can not well see through them.

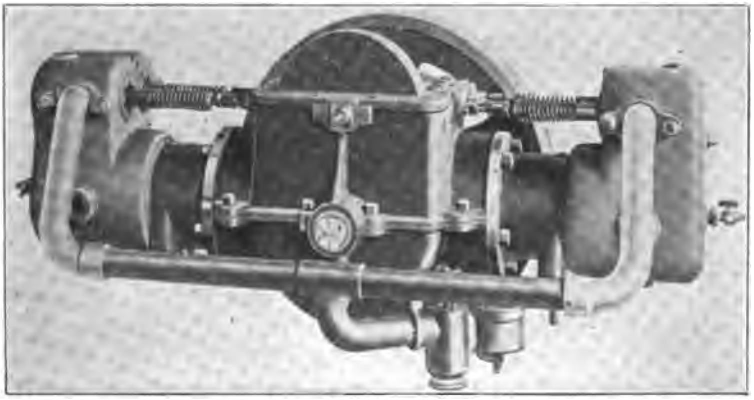


Fig. 69. Double Opposed Motor.

Location of Mechanism. Several arrangements of mechanism are in use. In the earlier forms the motors were placed under the operator's seat because this was near to the driven axle and was the most available space unused by the passengers. As motors increased in size this space was not sufficient, so the body of the vehicle was extended backward, the full height of the seat, giving much additional room. Additional passengers were either placed in front or on top of this rear extension, with the result that, as motors were made still larger, they were crowded down under the floor in a dark and inaccessible position as well as exposed to the mud and dust of the road. These faults compelled recognition, and, coupled with the unpleasant riding qualities of the front end, caused the motor to be placed at the front with the transmission gear and similar fittings under the floor as in common use at present. In a few instances designers were able to provide sufficient power in the space under the seat and thus avoided placing the motor in front, far removed from its point of application of power, and the success of such arrangement with the success of rear-placed motors renders it likely that in the near future the motor at the rear will be considered, as it undoubtedly is, the best engineering practice.

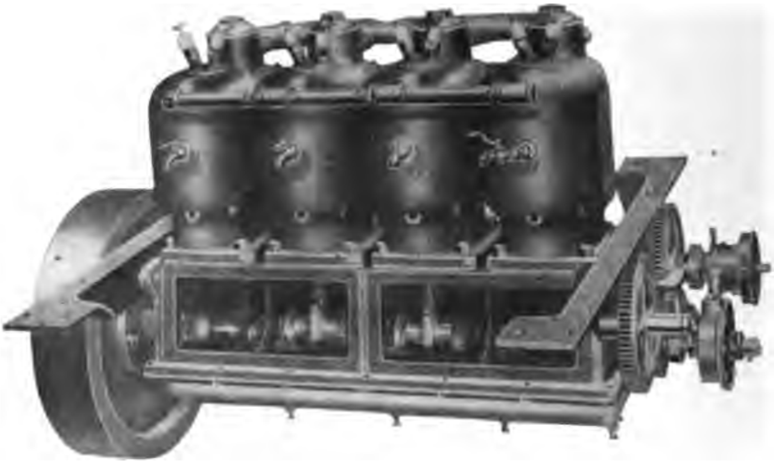


Fig. 70 Vertical Four-Cylinder Engine.

Most designers began by using single-cylinder motors which were placed horizontally lengthwise of the vehicle, because this placing secures low center of gravity and least vibration. Increased power was secured by doubling the cylinders, but since a twin motor of the four-cycle type ignites in irregular sequence if the cranks are opposed, the double opposed motor became the accepted two-cylinder form. This ignites one cylinder each revolution instead of one and one-half revolution followed by one-half revolution apart, as in the twin-cylinder type.

Doubling the twin motor gave the common four-cylinder engine, usually placed vertically, with crank shaft lengthwise the vehicle. The reason for this arrangement is that the width of an ordinary vehicle is not sufficient to place the motor crosswise, with crank shaft parallel to rear axle, as in the single and double cylinder arrangement. The triple cylinder motor is used by some makers who believe that it secures multiple cylinder results with the least complication and is therefore the most desirable form. Such engines, with cylinders of 5-inch bore, are placed crosswise of the vehicle as in the Duryea while four cylinders of nearly 4-inch bore are placed crosswise at the front in one or two air cooled vehicles, as in the Marion. But the usual arrangement is lengthwise of the vehicle in vertical position when more than two cylinders are used. In the Marmon the cylinders are inclined two to each side about 30 degrees from a vertical position, while in the Duryea, the cylinders are inclined to the rear, 30 degrees from horizontal. In the Adams-Farwell, either three or five cylinders are used, equally spaced around a vertical axis and arranged to revolve in a horizontal plane. The weight of the cylinders avoids need for a fly wheel and their motion gives an efficient air cooling without fans or other mechanism.

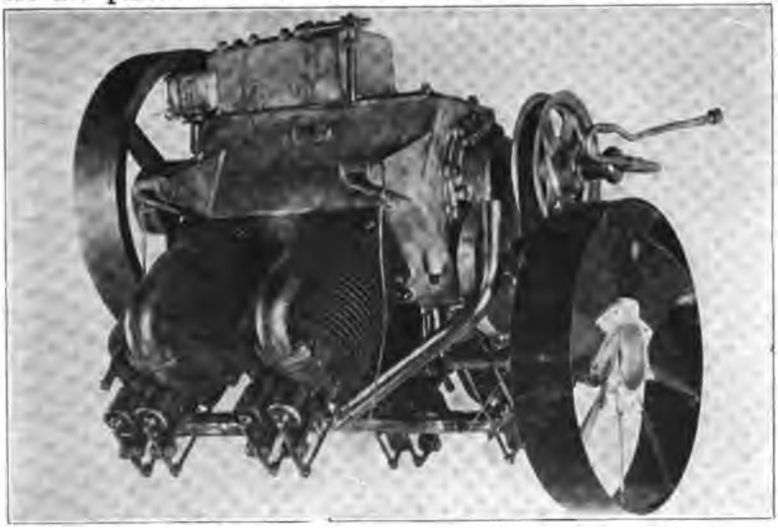


Fig. 71. Marmon Inclined-Cylinder Engine.

In one or more instances the cylinders have been placed equally distant around their axis of revolution and parallel thereto, which arrangement also secures steady rotation without a fly-wheel, and efficient air cooling. The auto is largely the sport of the wealthy and as is the case with all new things, is frequently provided, to the point of vulgarity, with various fittings and trimmings quite often made to sell rather than to use, and bought rather for ostentation than for any real service. A considerable business is done in these fittings, some of which are quite elaborate and expensive.

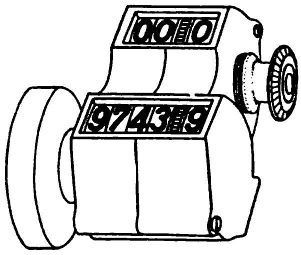


Fig. 72. Odometer.

FITTINGS.

Odometers are arranged with a single dial to give the total distance travelled or with a secondary dial to record the distance of each trip. Speed indicators show at a glance the speed at which the vehicle is traveling at any time, while clocks affixed to the dash board relieve the operator of the necessity of consulting his watch. Gradometers indicate the angle of the hill with more or less accuracy. Manometers tell the story of the water circulation. Voltmeters and ammeters advise concerning the electric circuit and various gauges and glasses show the action of the lubrication, the amount of fuel and water, and the air pressure in the air brake reservoir or gasolene tank as the case may be. Spark coils and acetylene generators, storage tanks and storage batteries are quite frequently in evidence while horns, gongs, or whistles complete the list. Some of the latter are numerous enough and properly toned and arranged to permit playing a tune. All are well in their place but add needlessly to an already

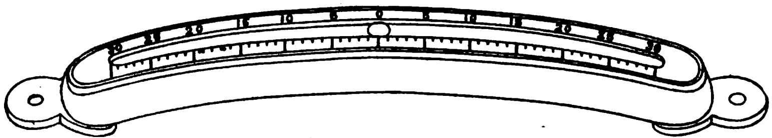


Fig. 73. Gradometer.

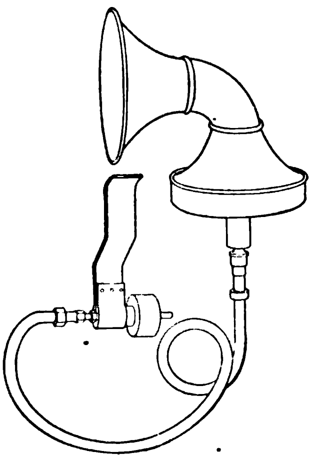


Fig. 74. Siren Horn.
A pulley running on the tire of the vehicle rapidly revolves a disk filled with holes. The result is a loud sound.

complicated vehicle and are not in accord with the simplicity which must accompany an extended use of this valuable invention.

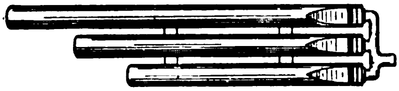


Fig. 75. Three-Toned Horn.

SHOCK ABSORBERS.

The high speeds frequently attained by motor vehicles greatly magnify inequalities of the road surface, with the result that the springs are violently compressed and rebound disagreeably, sometimes breaking. To prevent this, friction surfaces have been applied, which, while they permit yielding, dampen or deaden the spring action and render the vehicle more comfortable. Some forms of these employ pistons with valves or passages which permit free movement in one direction, but not in the other. It is urged against this that at high speed the second inequality is met before the springs have recovered their position, so they are unable to perform their duty.

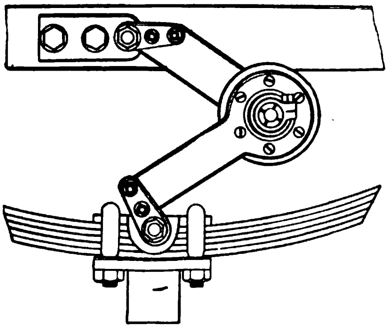


Fig. 76. Shock Absorber.

Springs. The comfort and durability of the vehicle depends largely upon the springs, although following cycle practice, many constructors have depended upon tires for this service. As in carriages, three forms of springs are quite common with a number of less used forms. The full elliptic has always had recognition and is a serviceable spring, but does not offer the rigidity sidewise that the half elliptic secures. It is quite essential that ther ear axle at its sprocket should remain in line with the body or frame which carries the front sprocket, as otherwise the chain may jump off. The full elliptic requires the use of reaches or radius rods to hold the axle in position, but the semi-elliptic is usually fastened to the framework at one end, while the other end is carried by a swinging shackle. Side springs fastened to the body at their centers, and to the axle at their ends, have been much used on cheap constructions, and although not the best form, have given good service.

Spirial springs are sometimes used, principally as an accessory, to modify the action of the main spring or to assist it to carry the load. The high speeds frequently attained by autos, together with the small wheels used, demand exceptionally good spring suspension, which has heretofore been neglected, but is receiving more attention at present. Rubber buffers have been frequently used to prevent overloaded springs, and many a bent or broken axle has been due to improper spring design. In case of a broken spring it is usually possible to fill in the space with a block of wood which will permit the vehicle to be used.

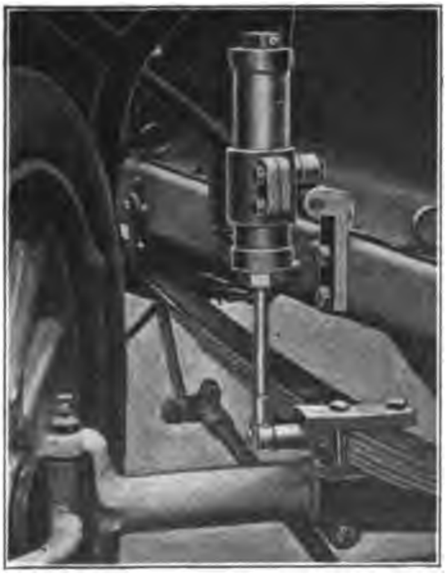


Fig. 77. Air-Cushion Shock Absorber.

Much of the comfort of a vehicle depends upon the upholstering. Deep springs in the cushions and backs add greatly to the ease of riding. This is particularly true in going over gutters or water bars where stiff, firm backs, as found in many tonneaus, transmit to the rider severe jolts, which, if the backs are high, are felt as disagreeable jerks at the neck. For high speed, low backs are more comfortable because they permit the entire spinal column to yield instead of the neck only. Deep springs, however, ease such objectionable features greatly.

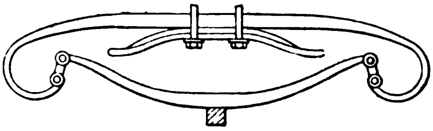
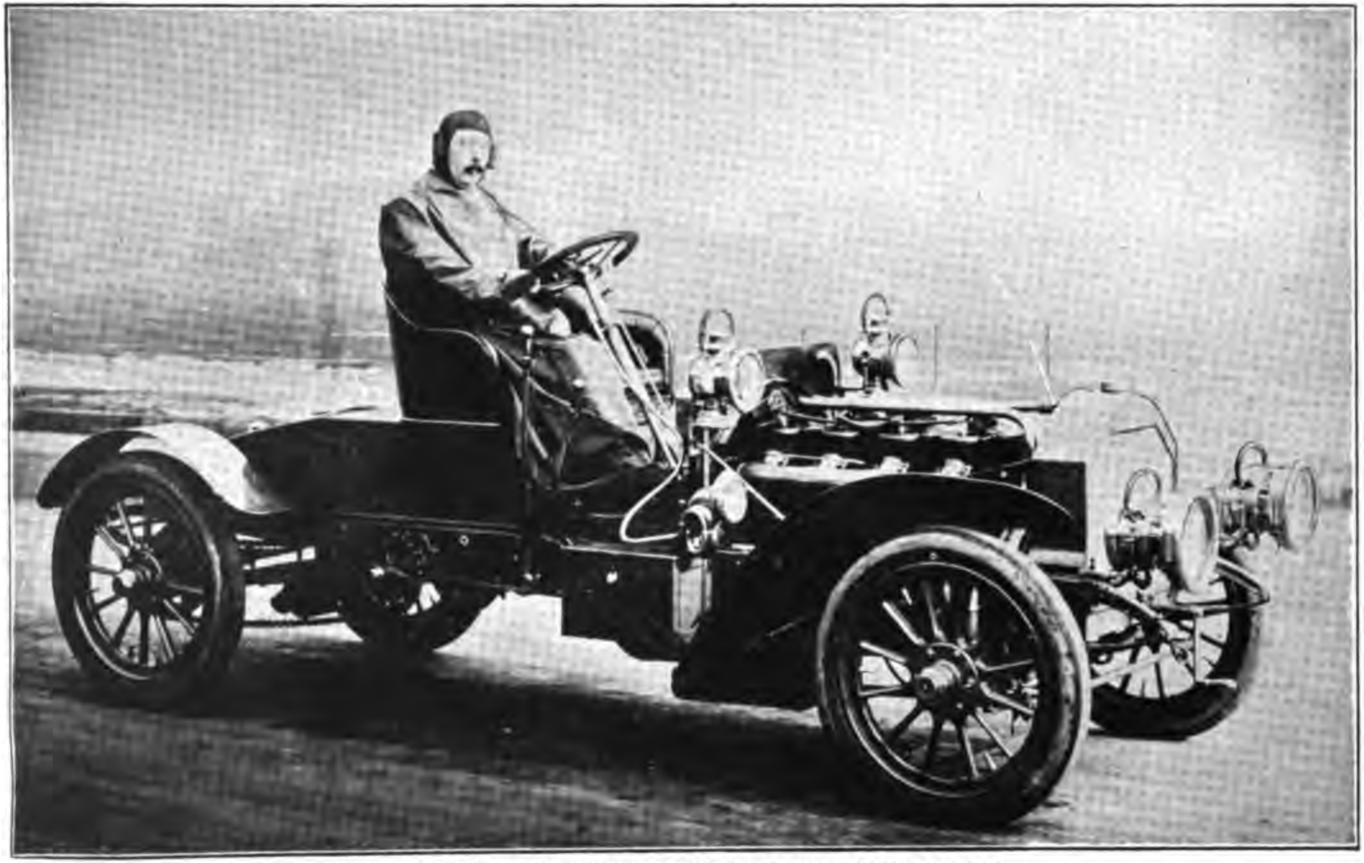


Fig. 78. Rear Spring with Buffer.

Since the auto is necessarily associated with oil, and is driven at high speeds in all weathers, the upholstering is best of leather or pantasote, so that it may not absorb oil nor dirt nor be soaked and damaged by water.

BEARINGS.

Auto bearings are in general of three kinds, plain, ball and roller. The plain or common carriage bearing gives good satisfac-



APPERSON 100 HORSE-POWER RUNABOUT, PRICE $11,500
The most expensive automobile of domestic manufacture shown at the Chicago Automobile Show, 1906

tion if frequently oiled and is of low first cost and needs few repairs. Rear axles which revolve are frequently mounted in plain bearings, usually of bronze or babbitt, with equally good results. For light vehicles, particularly with small power, as the light steam and electric carriages, ball bearings are quite common. The small area of the ball races requires that the balls, cups and cones be extremely hard in order to give service, and a broken ball frequently damages the bearing. The operator should listen for grinding or squeaking in the ball bearings and stop and remove the broken ball before further damage is done. For heavier loads, roller bearings are common. These are of several varieties, one well known form employing flexible rollers made by rolling a strip of metal into a spiral. The rollers are usually guided by cages to keep them parallel, and if not so guided should be quite short, preferably of a length not greater than their diameter. Rollers are usually hardened and ground. Conical rollers, also held in cages, are much used and are particularly adapted for places where the strain comes in various directions, as in the hubs of wheels. Ball or roller

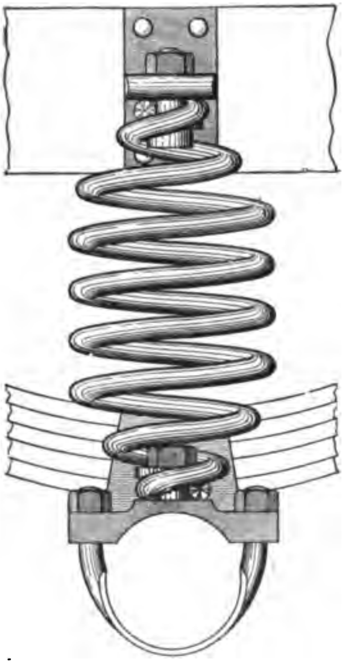


Fig. 79. Spiral Equalizing Spring.

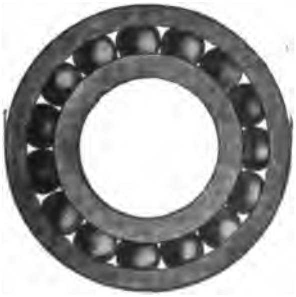


Fig. 80. Ball Bearing.

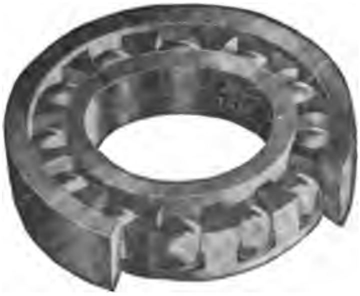


Fig. 81. Annular Ball Bearing.

bearings are much used to receive the thrust of bevel gears or friction disks.

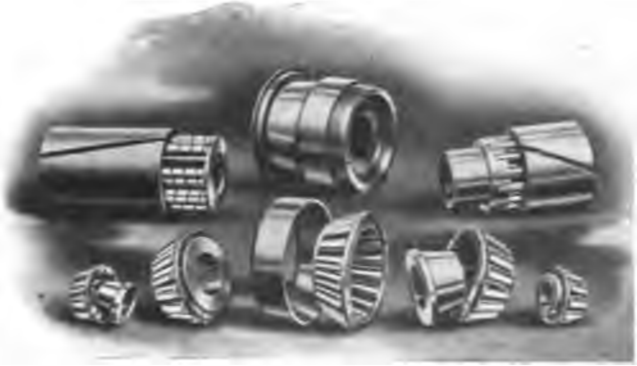


Fig. 82. Plain, Flexible, and Conical Roller Bearings.

LAMPS.

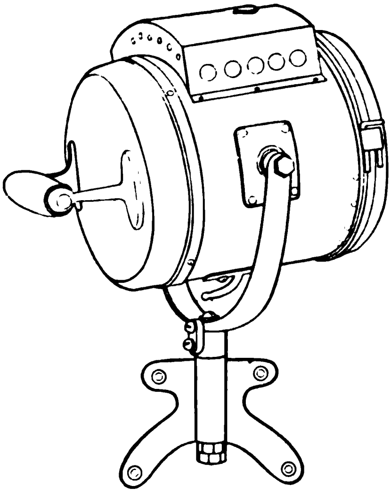


Fig. 83. Automobile Searchlight.

The law in most places requires autos to carry lamps, although other vehicles do not as a rule carry them and cannot be seen by the auto driver unless he is provided with a searchlight able to light the road a great distance ahead. Without this assistance he may be unaware that a scary horse is doing damage and therefore unable to stop or govern himself accordingly. The searchlight throws a powerful beam which blinds the horse driver and renders him likely to leave the road. The safest arrangement is for all vehicles to carry a light on dark roads in order that each driver may be aware of the presence of the other.

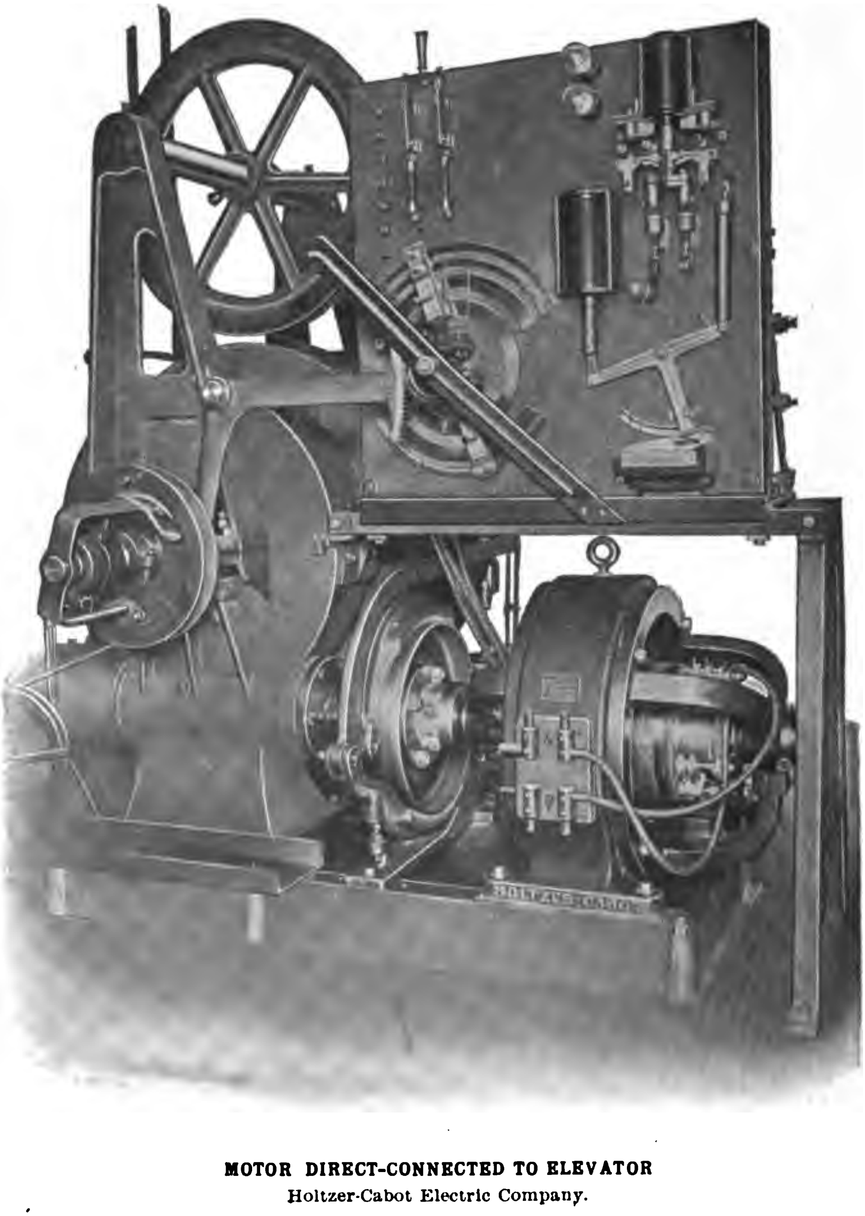
OPERATION.

The operation of a vehicle depends much upon its particular design and information is usually supplied by the maker. In general, it is necessary to turn on the electric current, the liquid fuel, open the throttle, and turn the starting crank. After the motor starts, adjust the gasolene to give best results, throttle the motor to suit, and set the low clutch gently. This throws a load on the the motor, to overcome which the throttle should be opened correspondingly. As the vehicle starts, feel of the steering to know that the vehicle is under control. As the speed increases change to a higher gear, the object of the skilled driver being to use the high gear as much as possible, in order that the motor may make as few revolutions per mile as may be, thus saving fuel and wear. In no event should the motor be choked down till it is jerky or liable to stop, for this may result in a stop in front of a train or in some similar dangerous and undesirable place.

The brake should be tested at the first opportunity and particularly before starting down a steep hill, so that it may be known to be in perfect order, for next to the ability to go, is the ability to control and stop. If the brake is faulty, the vehicle may be stopped by stopping the motor with the low speed clutch engaged and the clutch may also be used as a brake either instead of the regular brake or in conjunction with it on hills, thus forming a second brake, and one that is usually in order, as proved by the ability to climb hills. The low clutch is very effective and subjects the vehicle to a decided strain on which account it should be applied gently lest a chain be broken or gears stripped. In such an event the vehicle should be turned crosswise the road into the bank if circumstances permit. If the speed is too fast and the road is clear, and straight, the bottom of a hill may be safely reached but this dangerous chance should never be attempted except as a last resort. A properly powered vehicle will climb hills with little loss of time, so there is no need to rush down hill at a dangerous rate or with the vehicle beyond control to make up time.

The operator should learn to recognize by ear the proper running of all parts of the vehicle and recognize instantly any deviation therefrom. He should also recognize by the way the vehicle starts or coasts whether it runs freely or not, and by the feel whether a tire is flat or not. Lack of lubrication in the engine or vehicle adds much to the labor and expense and should be sought for and remedied. A weak spark causes a weak engine and signifies that either the batteries need renewal, the generator brushes need cleaning, the driving device is not doing its duty, or the electrical wires and connections are at fault. An excess of lubricating oil will sometimes coat the interior of the cylinder with carbon, which should be removed by scraping, the cylinder heads being taken out for this purpose. The mixture should be right and the proper proportion of gasolene vapor and air must be determined by adjustment and trial. Usually more is required on a dry day than on a wet day because on a wet day the water vapor displaces some of the oxygen, so that less gasolene can be burned. Too much fuel weakens the mixture and soots the plugs and walls.

The cooling devices should be watched that the fan does not stop nor the water tank get empty, although in either case the engine may be run a short distance without damage before it gets hot enough to destroy the lubrication. The gasolene tank and piping should be so simple that it can be easily watched, for a leak is not only wasteful, but dangerous, because of possible fire. The tank should never be exposed to heat or burning vapor and tanks containing pressure are inadvisable because of the more rapid leak in such cases. For cold weather or for starting, a gasolene of low specific gravity, numbered high on the Baumé scale, is best, but a heavier liquid will give more power per gallon. With a hot engine, kerosene can generally be used, a fact which will enable one sometimes to get home after finding the gasolene tank empty. Take great care that the battery is never left on a closed circuit for this quickly destroys its efficiency.



MOTOR DIRECT-CONNECTED TO ELEVATOR
Holtzer-Cabot Electric Company.

ELEVATORS

The elevator as a modern appliance has become a very important factor in business life. Fifty years ago it was comparatively unnecessary, and in the few instances in which it was in use, it was considered more of a luxury than a necessity. The earliest form of elevator was used only for merchandise, and the power employed was derived from a revolving shaft through the medium of leather belts running over pulleys. The introduction of steam, however, as a source of power for its operation, made a change in the speed that could be attained, and enlarged considerably its field of operation. It then began to be used for passengers as well as goods.

EARLY STEAM ELEVATORS

The application of steam for this purpose was made in a modified form, the engine employed being a double cylinder engine with the cranks set at right angles to avoid centering, but the valve motion was the principal feature of difference. Of course, many experiments were tried in the beginning, but what we shall describe here is that form of valve motion which became generally adopted. The distributing valves were of a special type, resembling more than anything one ordinary D-valve within another, and the number of ports in the cylinders were four each; Nos. 1 and 3 being the usual distributing ports carrying steam to each end of the cylinder, and Nos. 2 and 4 being used alternately as steam and exhaust ports. The starting and stopping was done by means of a change valve, which alternately, at the will of the operator, converted one of the latter mentioned ports into a steam supply port and the other into

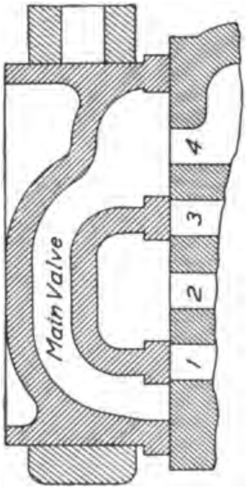


Fig. 1. Distributing Valve.

an exhaust. These valves — one change and two distributing — were all three contained within one steam chest, and the pressure of the steam from the boiler was always on them, holding them to their seats. The change valve, however, was the only one which opened a port directly into the steam chest. The operation of these valves and their arrangement will be readily seen by reference to the accompanying illustration.

It will be seen from the illustration that with this arrangement of valves there could be no lap or lead in the distributing valves on the cylinder faces, because the valves had to act alternately for steam supply and exhaust, and any lap or lead that might be given them for operation in one direction would produce a distorted action when used for running in the reverse direction. The consequence was that the engine of this type was not economical in its use of steam; and while it was a great favorite at the time of its introduction, and for many years afterward (because of a lack of anything better) it has, since the introduction of the

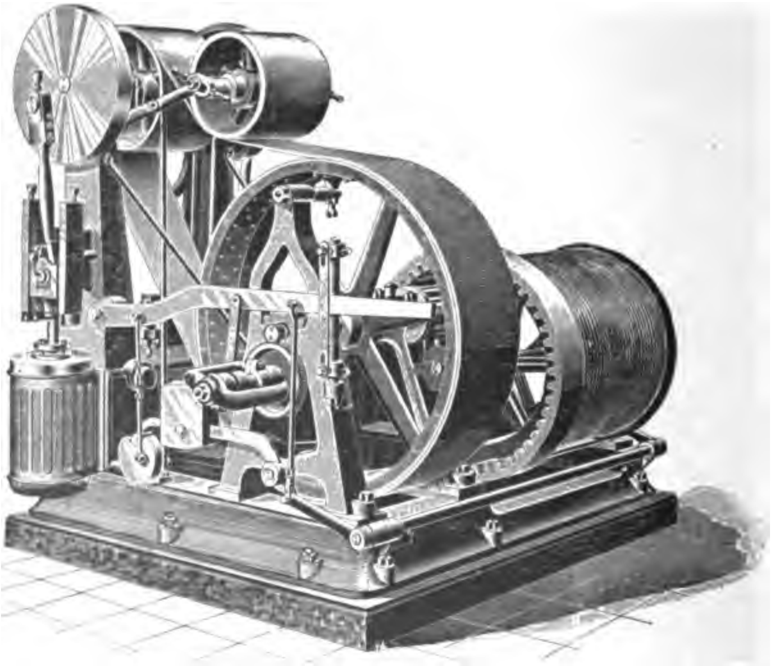


Fig. 2. Spur-Gear Elevator Engine.

hydraulic and modern types of electric elevators, almost gone out of use.

At the time of its introduction it was used entirely in connection with spur gearing, the first types of this engine being made to drive a pulley on the crank shaft which was belted to a larger pulley running in stands on the engine bed, the shaft which this pulley drove having on its end a spur pinion meshing into an internal gear, which was bolted to the end of a hoisting drum or spool which wound up the cable or wire rope, to one end of which the traveling platform or cage was attached. This wire rope passed from the hoisting drum up the hatchway and over grooved wheels or sheaves at the top of hatchway and then down to the cage, and the change valve, by means of which the steam was shut off or turned into the engine to operate it in either direction, was connected to a wire rope of smaller diameter, which led up the hatchway within easy reach of the operator, and the pulling of this rope up or down was sufficient to start the elevator in either direction.

The amount of steam, however, under pressure, required to operate the engine when lowering a load, was so much less than that needed for hoisting, that in order to prevent the engine from racing and lowering at an undue speed, the change valve was always adjusted to give a very small opening into the steam supply when running in this direction, and in addition to that a certain amount of lap had to be given to the valve on the exhaust side, so as to choke the exhaust and thereby retard the descent. There was some danger of overloading of the engine, for in case an overload was placed on the cage, of course an attempt to lift it would fail, but in lowering, especially when the steam was shut off quickly, the pressure of the confined steam in the cylinders would sometimes exceed that in the steam chest, in which case the distributing valves on the cylinders would be lifted from their seats, and where they were fitted to work in a yoke or buckle, at the end of the valve stem, they would remain off the seat, when once lifted therefrom, until replaced. There was nothing then to hold the load but the brake, and to obviate this trouble it was customary in many cases to bolt to the bottom part of the steam chest an angle piece fitting closely at the back of the valve. This piece being stationary, and its vertical side parallel with the cylinder face, the valve worked up and down between it and the valve seat, and it prevented the valve from being raised from its seat.

The brake used on this type of engine was a flexible band of steel, which was lined with hard maple in short sections and fastened to the band by screws. A suitable lever for applying the brake, with a heavy cast-iron weight on the end of the lever and proper adjustments for taking up the wear, completed the outfit. The brake was always applied by means of the weight on the end of the brake lever and was released by means of a heart-shaped cam fastened to a pedestal or stand on the engine bed and operated by the yoke or automatic stop, which, being connected to the operating cable in the hatchway, before described, was always actuated when the hand cable was pulled to the center of its throw.

The pistons of these engines were usually very simple in construction; they consisted of a disc or block of cast iron properly bored and fitted to the piston rod and turned with grooves to receive the piston rings, which were then sprung over the block into their respective grooves. They were made slightly eccentric, being thicker on the side which was left uncut, and were usually turned little larger than the bore of the cylinder. When they were cut, a piece had to be taken out, leaving a space of about $\frac{3}{16}$ inch between the cut ends, and the rings consequently had to be squeezed together or compressed in order to enter the ends of the cylinder, and this caused a constant outward pressure of the piston rings. They were made two in number; in some cases three, and were usually from $\frac{3}{8}$ to $\frac{5}{8}$ inch wide.

Owing to the confined space into which these engines had to be put at times, it became necessary to reduce them somewhat in height in order to get them into low basements when desired. The consequence was that the connecting rods were not always as long as the best practice would dictate, and as a consequence of this, and the constant reversing of the engine, it was frequently found somewhat difficult to make them run quiet. Now, however, with care, this result can generally be attained.

Another cause of hammering in this type of engine was a lack of care on the part of the manufacturer to so proportion the length of bore of cylinder as to allow the outer piston rings to just pass over the end of the bore at the end of each stroke. This length of bore, of course, was determined at the time of counterboring the cylinders, and where the bore was sò long that the piston rings did not quite reach the ends of it, they would in time, as the bore of the cylinder enlarged from constant wear, leave a shoulder at each end. Against this shoulder the rings would strike at the end of each stroke, and if the engineer was not posted on this peculiarity, he would probably try for months to get his rods to run perfectly quiet without good results. The only remedy in a case of this kind would be to take out the pistons and file the shoulders, before mentioned, but it would be only temporary. The proper way to get rid of the evil entirely would be to counterbore the cylinders a little more, but it was a job that was attended with considerable difficulty with the engine in place, hence the first method would be found most satisfactory.

The cross-heads and guides were similar to those of most engines, whether horizontal or vertical, and differed with the ideas and taste of the maker. Several different arrangements were used; some with plain straight slides, some with V-shaped; but the most popular was that of the bored guides, for cross heads, using a bronze shoe with proper adjustments for wear. These engines would often run as high as 500 r. p. m. at full speed.

One feature of this engine which frequently caused great annoyance was the running off of the belt which connected the pulley on the crank or engine shaft with the large pulley, before mentioned, running on a shaft in stands on the bed. There would seem at first sight to be no good reason why a belt of this kind should not run well and in line, but frequently carelessness in workmanship was the cause of this, for if the pulleys themselves were of equal diameter at each side, and the shafts were not perfectly aligned with one another, it would cause this trouble; and while the belt might be adjusted to run well in one direction, it would run off the pulley when the engine was reversed, there being a "tightener" for the purpose of taking up the slack of the belt, which could be adjusted so as to cause the belt to run well in one direction. The distance between centers of shafts being short, the belt was necessarily short too, seldom exceeding 19 feet in entire length. and it was always endless, that is, without seam or lacing.

The writer has frequently seen on some of the older types of these engines a pulley that was larger on one side than the other; this also would cause the trouble.

Another defect in this engine was the liability, when the belt had been in use a great while and neglected, for it to become dry and cracked, and if it broke either when lifting or lowering a heavy load, there was a chance of the cage falling, there being nothing to hold it in that case but the brake. To automatically apply the brake and at the same time shut off steam, in case of an accident of this nature, there was attached, to one of the arms carrying the idler, a vertical rod The lower end was attached to the cam operating the brake; the upper part of this rod was hollow and the lower part telescoped into it. A collar and set screw on the lower rod being set in the proper position would receive the end of the upper rod on its face, in case the belt should break or come apart, for the great weight of the idler pulley would cause it to fall, carrying the arm to which the upper part of this rod was attached. This then would throw the brake cam around in the position to apply the brake, and at the same time shut off the steam, thus stopping the engine also.

This pulley, which performed the double office of tightener and as an adjustment for the direction of the belt, was very necessary, because as the belt stretched from constant use, this idler, running on top of it, and being made very heavy for the purpose, would take up the slack of the belt, causing it to have greater contact with the pulleys. The arms, which carried the shaft upon which it ran, were attached to the upper part of the engine frame and extended outwards toward the rear of the engine, and were of such a length as to leave the pulley in the right position upon the belt just between the engine pulley and the larger pulley in the stands on the engine bed. Sometimes, however, a sudden stoppage of the engine would cause this tightener to jump away from the belt and then drop back upon it, and this feature had a tendency to cause the belt to break whenever it became weakened in any part.

To prevent this jumping of the idler, which also had a bad effect on the stopping of the engine, spiral springs were sometimes attached to these arms and carried down to a convenient point below where they were attached either to the bed of the engine, or to the wrought-iron braces which stayed the upright frame to the bed. Turn buckles were provided to give the springs proper tension, and this remedied the difficulty just related.

When these engines were at rest the steam chest was always full of steam and ready at any moment to start upon the change valve being opened in the proper direction. As this steam chest radiated considerable heat, there was always more or less water of condensation in it. A drain pipe was run from the bottom of the steam chest to a steam trap, which was set considerably below the level of the bottom of steam chest, and the water escaped to this steam trap.

The automatic stop was a screw provided with a traveling nut and adjustable set collars. This screw was a sleeve which usually ran upon a long stud bolted to one of the stands in which the larger pulley shaft ran, and it was geared to the pulley shaft by means of a spur gear and pinion, which were so proportioned as to give this automatic screw about the same speed as the drum shaft. The traveling nut was so arranged that at either end of the run it would

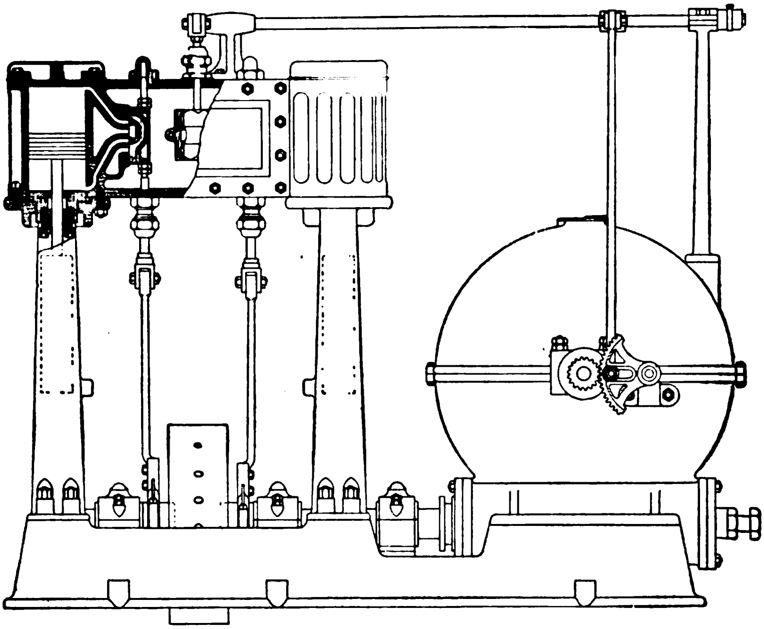


Fig. 3. Elevator Engine with Worm Gear.

come in contact with the set collars, which had to be set just to the right position to gear with this traveling nut. They each had a tooth which interlocked when the traveling nut and collar were brought together. By this means, the traveling nut was made to revolve, and as it turned, the automatic yoke, which was connected to the starting lever by means of a link connection, operated the change valve and applied the brake at the same time, thereby stopping the engine at the limit of its run. This end was also attained by means of stop buttons on the operating cable, which were made so as to clamp the cable wherever they were placed and tightened up, and a striker or arm attached to the cage so as to slide up and down on the operating cable freely. Whenever the striker came in contact with one of these stop buttons it pulled the cable the same as the attendant would, and thereby also shut off steam and applied the brake. The operations were identical in each case, except in the method of arriving at results. A pressure of from 60 to 90 pounds of steam was usually carried at the boiler.

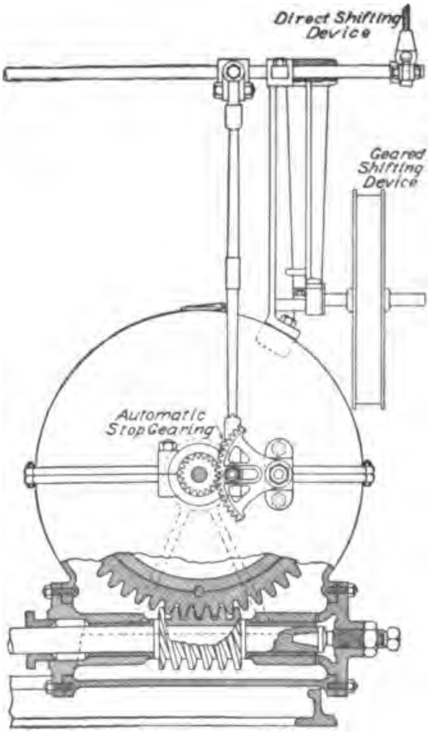


Fig. 4. Worm Gear in Housing.

The lubrication of the wrist and cross head pins, eccentric straps, etc., was usually supplied by means of compression grease cups. This method was adopted on the score of economy and cleanliness; the valves were lubricated by means of a self-feeding cylinder lubricator.

The chief difficulty with the spur gear type of engine was that of low pressure and overloading. It sometimes happened that when there was no steam on the engine at all, the car being left at one of the upper stories, an ignorant attendant would put load on the car and pull the operating cable. The brake being released, the load would run the engine backwards and run to the bottom violently. Of course, when these engines and their peculiarities became well known, accidents of this kind were less frequent, and taking it altogether, the service rendered by these engines was invaluable. Being the most rapid up to the time of their introduction and for a long time afterward, they were a favorite for many years, the principal objection to them being the cost of operation in comparison with other methods introduced later.

Later on a modification of this engine was used for passenger service. The changes consisted of the use of a worm gear in place of the spur gearing just described, and owing to the location of the worm shaft it necessitated the use of an engine with the cylinders inverted, and placed at the top of the engine instead of below as in the original form. This arrangement has some advantages for passenger work, as the liability to run down, which always exists with a hoisting machine where spur gearing is used, was eliminated. It was also considered safer and more desirable for passenger use on account of its smoother action and the fact that the breakage of one or two teeth in the gear would not cause the platform to descend rapidly. The other characteristics of the engine were not changed.

WATER BALANCE ELEVATOR

Contemporary with this engine, which attained its greatest popularity during the 70's, there was introduced a form of hydraulic elevator which at one time bid fair to be a successful rival of the steam engine. It was called the water balance elevator. It consisted of the usual cage or cab in which the passengers rode, the cables necessary for hoisting which passed up the top of the hatchway in the usual manner and over sheaves, thence down into a large metal tube or well hole, and attached to the other end of these cables was a large bucket that nearly filled the well hole just mentioned. At the top of the well hole and above the highest point to which the bucket traveled, there was a tank containing water supplied by means of a steam pump. At the bottom of the bucket was a discharge valve, which as well as the valve at the bottom of the tank just mentioned, were operated by means of pedals located in the cab.

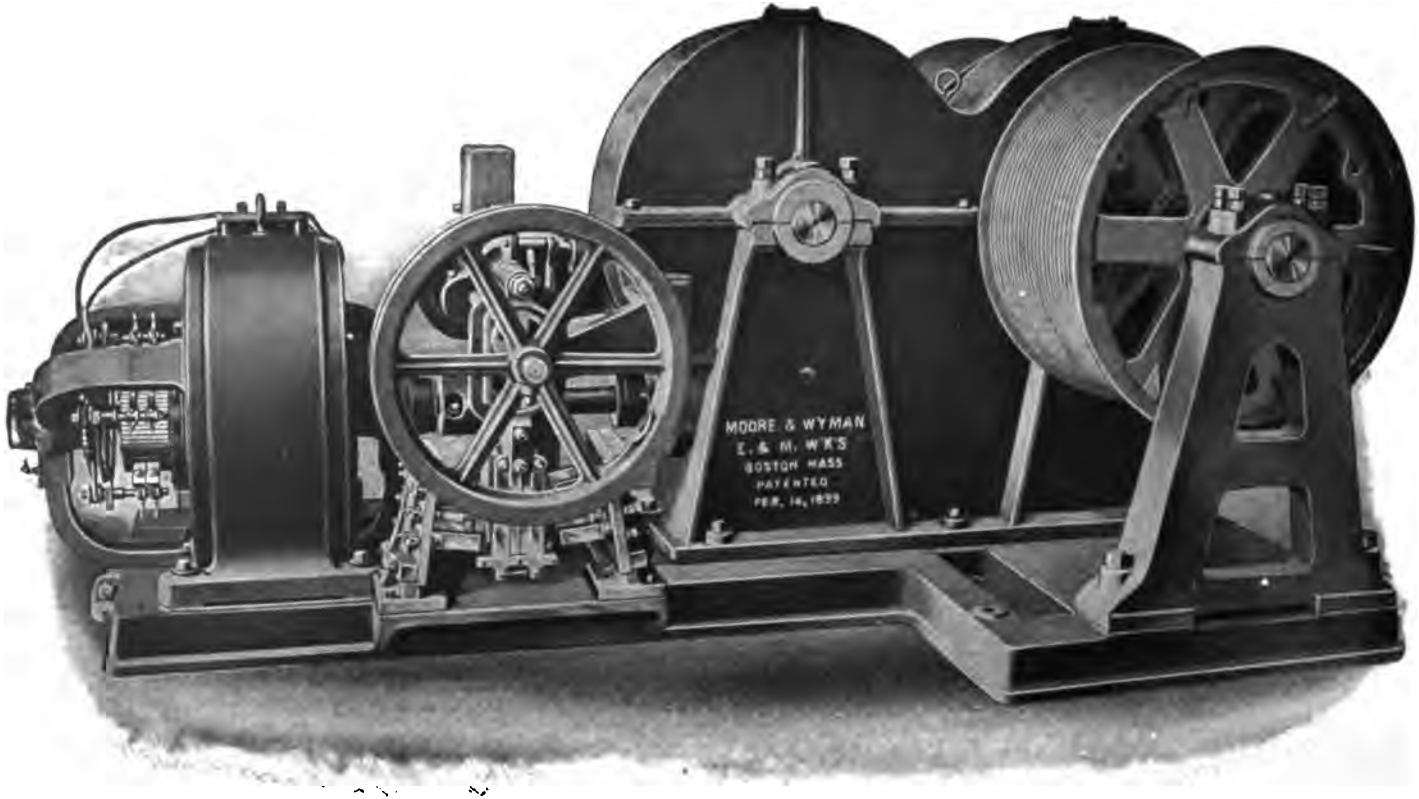
The operator by pressing the appropriate pedal with his foot would discharge water into the bucket from the tank above. When sufficient water had accumulated in the bucket to more than balance the weight of the cage and its occupants, the elevator would begin to move, the water in the bucket forming a counterbalance weight and virtually dropping down the well hole dragging the cage upwards, and vice versa, when the water was allowed to discharge itself from the bucket it would become lighter than the cage and the cage would drop. This water having been discharged into a tank at the bottom of the well hole, would be pumped again into the overhead tank.

The speed of this elevator was unlimited, and was governed entirely by the use of a powerful brake gripping the slides or rails on which the cage traveled. This brake was arranged by means of very strong springs which always held the brake on, and had to be released and held off by hand to obtain any movement of the cab when the conditions for motion were right; and in letting go of the brake, it applied itself with sufficient power to stop the elevator.

This form of elevator was found to be very expensive, both to install and operate, and moreover, was dangerous in the hands of unskilled men, and it soon went out of favor upon the introduction of the horizontal hydraulic elevator. The latter was originally the invention of William Armstrong, a man prominent among mechanical engineers in Great Britain.

HORIZONTAL HYDRAULIC ELEVATORS

The first elevator of this type was used for the purpose of hoisting stones from a quarry in Yorkshire, but its utility as an elevator for merchandise was soon recognized and it began to be used extensively for this purpose in that country, and it was along in the early '70's that it was first introduced into the United States. The earlier machines of this type were usually operated by water pressure obtained from the city mains. The machine consisted of a cast iron cylinder, the bore and length of which varied according to surrounding conditions, being chiefly governed by the water



STANDARD ELEVATOR MOTOR. DIRECT-CONNECTED.

Holtzer-Cabot Electric Company.

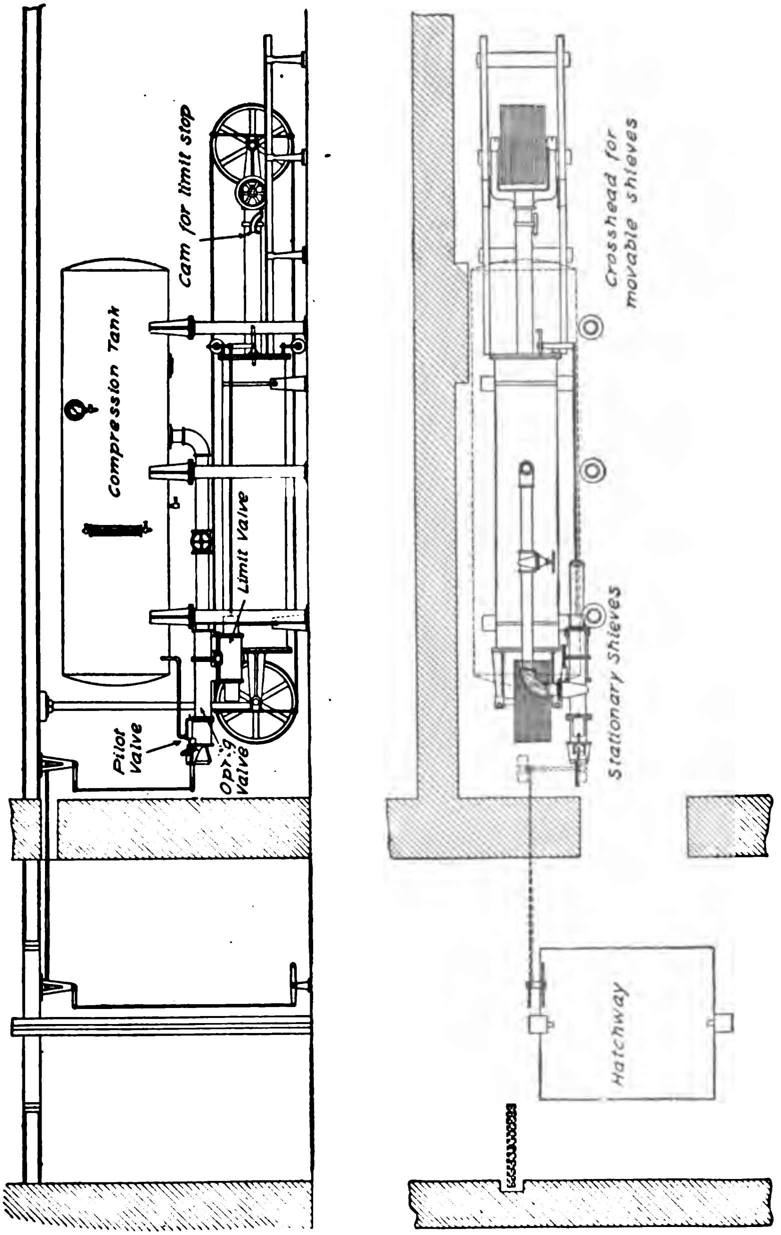


Fig. 5. Plan and Elevation of Horizontal Hydraulic Elevator.

pressure available and the height of the building in which it was used. A piston, fitting closely in this cylinder, was made water tight by means of suitable packing. There was a piston rod and cross head which carried a set of traveling sheaves, and a set of fixed sheaves. The cross head traveled on a track provided for the purpose, which acted both as a support and guide for same. The cable which hoisted and lowered the cage, passed up the hatchway in the usual manner over sheaves at the top of same, thence down to one of the fixed sheaves below on the end of the machine. From there it passed successively along under the machine, around one of the movable sheaves on the cross head, back to one of the fixed sheaves at end of machine and so on three or four times, and the other end was finally made fast to the hydraulic engine. This arrangement of rope and sheaves was exactly like a block and tackle, the cage being attached to the loose or running end of the rope. Now when water pressure was applied to the piston, it would pull these sheaves apart, causing the end of the cable in the hatchway to raise, with the cage attached, at a speed much faster than that at which the piston traveled, the difference in speed being governed by the number of sheaves collectively on the machine. For instance, if the cross head had four movable sheaves traveling with it, and at the fixed end of the machine there were four sheaves, the ratio or difference between the speed of cage and that of the piston would be 8:1; in other words, the cage would travel eight times as fast as the piston, and eight times as far. The ratios more generally used are from 4:1 to 10:1, depending on the speed required and the load to be lifted. With this arrangement when

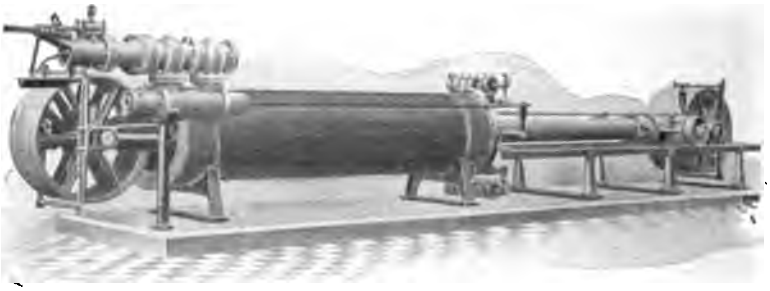


Fig. 6. Horizontal Hydraulic Elevator.

connected to the city mains, the water, after being used, was wasted or allowed to run to the sewer. Later on, the introduction of the roof tank permitted water to be used over and over again, the same as in the water balance elevator. A still greater advantage was gained by the introduction of what was called the pressure tank. This was a modification of the accumulator so much used in Europe in connection with hydraulic presses, and consisted of a reservoir that was fitted with a plunger of large area, which worked vertically through a tight stuffing box, and having on its end an enormous weight or load of cast iron. Water being pumped into this accumulator, raised the plunger with its load, and when draft was made upon it, it would force this water out into the cylinder of the hydraulic ram with a pressure equivalent to that of the load carried.

The pressure tank was similar in arrangement, except that the compression of air above the water gave the pressure required. A cylindrical tank properly braced and stayed was used, with inlet and outlet pipes and water glass to show the height of water in the tank, and a pressure gauge. Air would be pumped into the tank up to a moderate pressure, afterwards water would be pumped in, and this water further compressing the air, would produce an ultimate pressure of anywhere from 100 to 150 pounds per square inch. The inlet and outlet pipes for the water were directly at the bottom of the tank to prevent the escape of any of the air, and when water was drawn off from this tank in the cylinder of the hydraulic engine, the drop in pressure would not be more than a very few pounds, owing to the expansibility of the air above the water, about one-third of the total contents of the tank being air under pressure.

This arrangement enabled higher speeds than was admissible with the street main service, the street pressure of many cities being low; in fact those having a high pressure—anything from 60 to 100 pounds—being rare. Moreover this arrangement had other features which were desirable, the absence of water hammer in the pipes being one, the using of the same water over and over being another, and the ability to have the most useful pressure being a third. With the higher pressure, cylinders of a smaller diameter could be used, and consequently a less amount of water also.

The operation of the hydraulic elevator was by means of a two-way valve, the most improved type of which consisted of a cast iron cylinder with a brass lining, which was perforated opposite the openings or branch pipes in the cast iron body. Inside this brass lining was a plunger with leather cup packings held in position by discs of brass, which were so arranged as to cut off the supply of water gradually so as to produce an even and gentle stop. Where the supply was taken from the city main an additional precaution was taken of using an air chamber on the supply pipe near the operating valve. The office of this was to prevent violent shocks in the pipe from the sudden stoppage of the flow of water through the same, caused by shutting the operating valve quickly. The water in the main, when the valve was closed, would continue its onward course up into the air chamber, the air in which being compressed, would act similarly to a spring, gradually retarding the flow of the water and restoring its equilibrium, but in the case of the compression tank it acted of itself as a huge air chamber.

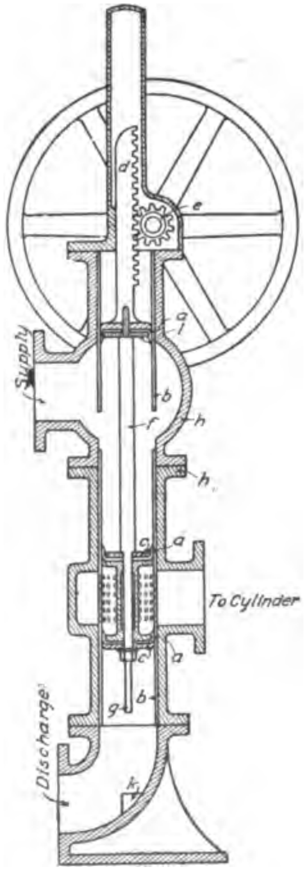


Fig. 7. Two-Way Operating Valve.

a, Leather packing cups; *b*, Brass lining of valve, *c*, Brass plates supporting leather cups; *d*, Brass rack in which pinion works to lift and depress the plunger; *e*, Steel pinion; *f*, Steel stem to which all the parts of the plunger are attached; *g*, Extended end of steel plunger which serves as a stop to downward stroke of plunger by striking on *k*; *h*, Cast iron body of valve.

Depressing the plunger allows the water to flow from supply to cylinder. Raising plunger allows water to discharge from cylinder.

With the higher pressure obtained by use of the tank, greater speeds could be attained, frequently as high as 300 or 400 feet per minute, while with the street main system it rarely exceeded 150 feet per minute, and frequently was as low as 50. The compression and roof tanks were usually kept supplied with water by means of powerful steam pumps, the change of level of water in the tanks being made to automatically turn on steam or shut it off. These pumps, therefore, were not obliged to run constantly, but only when the supply of water in the tanks became somewhat depleted, the pumps running simply long enough to supply the deficiency.

When the higher speeds were found desirable and attained, some better means of operating the elevators than the hand cable became a necessity, and the invention of the lever operating device followed. With it came the pilot valve. This was a small auxiliary valve attached to the main operating valve which obtained its power from the pressure tank. The operator in the cab moving his lever, would open the small pilot valve, which in turn admitted water to a piston on the stem of the main operating valve, the pressure of the water moving this piston in either direction as desired, and with it the main plunger of the operating valve. The pilot valve itself and its connection with the plunger of the main operating valve is so constructed that a partial movement of the operating lever would produce a partial opening of the pilot valve, and in turn, a partial opening of the main valve, if so desired. The full opening and closing were obtained by the full movement of the operating lever.

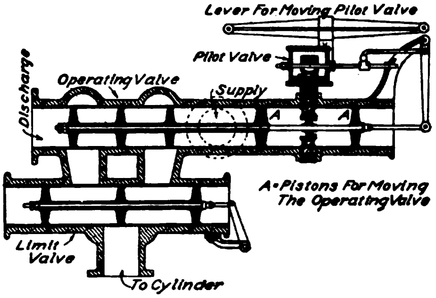

Lever For Moving Pilot Valve
Pilot Valve
Discharge
Operating Valve
Supply
A
A
A•Pistons For Moving The Operating Valve
Limit Valve
To Cylinder

Fig. 8. Auxiliary and Operating Valves.

VERTICAL HYDRAULIC ELEVATORS

The horizontal hydraulic elevator had not been in use very long, when Mr. C. W. Baldwin, of New York, conceived the idea of using a vertical cylinder. This was not entirely new, as they had been used in Europe, but not exactly in the manner in which he proposed to use his. The advantage of his form of hydraulic elevator was that it took up less room in the building, because it could be set up in the same hatchway with the traveling cage, in one corner of the well hole, and for the sake of economy in space it was usually made with a ratio of from 2:1 to 4:1, instead of from 6:1 to 10:1 as with the horizontal hydraulic. The consequence was that the cylinders were necessarily quite long, though smaller in diameter than the horizontal machine. They differed also from the horizontal in the fact that they did not use any guide ways for the cross head.

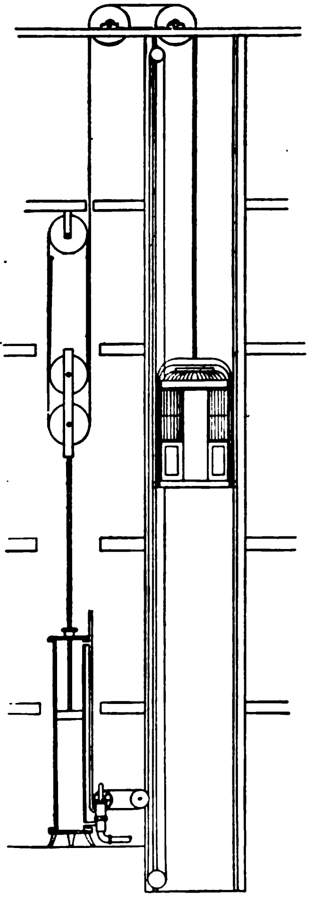


Fig. 9. Vertical Hydraulic Elevator.

The cylinder being set vertical and a fixed sheave directly above it, the end of the hoist cables were made fast to a beam overhead and led thence down to the cross head and around the sheave in same, and up again over the fixed sheave before mentioned, thence over the sheave in hatchway directly above cage. This gave the machine a speed ratio of 2 to 1, and the piston would travel just half the distance of the cage, but it was found that a great loss of pressure occurred at the beginning of the travel, owing to the top of the cylinder being so high above the level of supply. To equalize this, the discharged water was returned through a circulating pipe to the bottom of the piston, instead of discharging it into the surge tank or sewer immediately after it was used. By this means the weight of the water beneath the piston was used to equalize the pressure, but as this water beneath the piston was held there by atmospheric pressure until discharged, it was found that the length of the vertical cylinder could not be more than 33 feet at sea level, or its equivalent in other places. This limited the length of vertical cylinder that could be used, so that the ratio of this type of machine was governed somewhat by this.

But with all these machines, both horizontal and vertical, where the pressure was comparatively low, a great loss of power was caused by the friction of the piston in the cylinder, and the flow of the water through the pipes, as well as the difference in weight of the cables, depending on whether they were hanging in the hatchway on the side of the car or on that of the machine. These cables, which were usually four in number, and sometimes more (and generally of about $\frac{5}{8}$ inch diameter, weighing about $\frac{3}{4}$ of a pound to the foot), would, when the car or cage was at the top of the hatchway all hang down towards the machine, and in the case of a building say 100 feet high would amount to over 400 pounds. Now while as a measure of economy, it was desirable to counterbalance the weight of the cage, it could not be done very closely with this difference in the weight of the cables on one side or the other, according as the cage was at the lower or upper landing. Hence, some means of counteracting this was found desirable, and it was done by hanging chains in the hatchway, one end of them being attached to the wall of the hatchway about half way up the run or travel of the cage, their other ends being attached to the bottom of the cage. It will readily be seen that when the platform or cage was down at the bottom of the run, and consequently the cables on the car side hanging down in the hatchway and equalizing the weight of those on the other side, the chains would be hanging on the wall, but that when the cage was at the top of the hatchway and the weight of the cables preponderating on the other side, these chains would be hanging on the bottom of the cage, thus offsetting the weight of the cables. By this means closer counterpoising could be obtained, and the desirability of this method of counterpoising, in after years, when much taller buildings came into existence, may very readily be seen. In fact, it became quite indispensable in the case of buildings of 17 or 18 stories.

Later on, the introduction of the electric elevator and the claim made for its economy of operation caused elevator builders to look for more economical methods of operating the hydraulic elevators. One of the chief drawbacks to economy in the hydraulic elevator was the fact that the same amount of water had to be used per trip regardless of the load, and the introducers of the electric elevators made the claim that an amount of current proportional to the load carried was all that was used.

The introduction of the high pressure water system in the city of London had attracted considerable attention in engineering circles, and the use of elevators in connection therewith had shown that a greater economy was possible with a higher pressure, owing to reduced area of cylinder, there being less friction and smaller consumption of water. The system of high pressures was introduced here, but it has not realized all that was expected of it. The enormous expense connected with the installation and maintenance are the chief drawbacks, but during the time that was devoted to experimenting with the high pressure systems, one or two types of elevators were evolved that gave considerable satisfaction, one of these being that of using a vertical cylinder with a ram, the weight of which was sufficient to lift the cage with its load. The hoisting of the load, therefore, was done by discharging the water from the cylinder, and when the platform or cage was to be lowered it was accomplished by turning the water pressure against the end of the ram and lifting it. This ram was geared in the usual manner by means of a cross head and sheaves having a ratio of anywhere from 2:1 to 6:1.

Other schemes were devised for economy, one of which was to have two or more tanks at varying pressures, one tank having say 100 pounds pressure, a second 150, and using one or the other according to the load to be lifted, an automatic operating valve being used in connection therewith.

Another form of hydraulic elevator, which has always been very popular in Europe, was the plunger machine or ram. This consisted of a hollow plunger, which passed through a stuffing box in the top of the cylinder which was let down into the ground, the depth of same being the length of run from lower to upper landings, the platform or cage being set on top of this ram. When water was let into the cylinder the pressure of same against the bottom end of the ram forced it up out of the cylinder, and the cage with it, to the top of the building, the lowering being done by allowing the water to afterwards escape. The form of valve and its operation was the same in this case as in that of the other types of hydraulic elevators.

This style, of elevator, however, from the point of economy had one objectionable feature that was peculiar to itself, and which was more noticeable in the higher runs or upper stories of buildings. The plunger being hollow, to insure lightness, had a certain amount of buoyancy when wholly immersed, but when run partially or entirely out of the cylinder, this buoyancy necessarily decreased, and consequently the lifting power of the elevator became less and less as it reached the upper stories of the building. It consequently could not be counterbalanced very closely, because if that were done the plunger, in descending to the lower story, would come to a point where it would stop of itself because of its inability to displace the water in the cylinder. This was a matter that entered largely into the calculation of the area of plunger when arranging the proportions of cylinder and plunger, in relation to the pressure of water to be used.

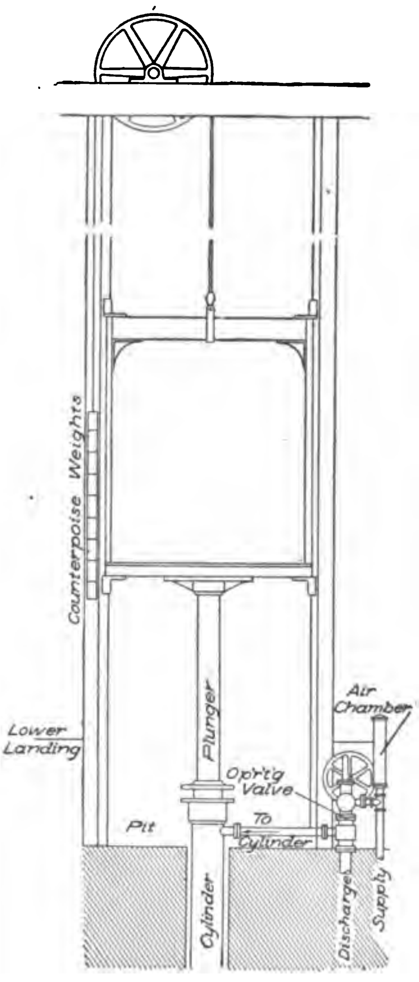


Fig. 10. Plunger Elevator.

The earlier elevators of this type were usually made with a cast-iron plunger, which as before stated, was hollow, and, owing to the brittleness of cast iron, had to be re-enforced by running a heavy wrought iron rod up through the middle of the plunger, the lower end passing through the bottom end of the plunger, the upper end being made fast to the floor of the cage. Without this the sudden opening of the operating valve would allow the escape of water from the cylinder for descent, and when the cage was in the upper story it was liable to cause the plunger to break off. Such an accident as this occurred some years ago in Paris, causing the loss of one or more lives.

In the case just mentioned, the wrought iron rod in the center of the plunger was absent, its absence being a fault in the design of the machine. To-day, however, with the introduction of Bessemer steel tubing, the necessity for the center rod does not exist, the ends of the tubes being threaded internally, and a male coupling being used inside the pipe. The joints in the cast iron plunger were made by boring out the ends of the sections of the plungers and inserting a thimble nicely fitted, which entered each end of the adjacent sections to a distance of 3 or 4 inches, the ends of the sections of the plunger themselves being faced or squared off perfectly in the lathe, and the whole being put together with a hydraulic cement composed of litharge and red lead mixed with boiled linseed oil, or Japan varnish. These machines are very much in vogue to-day for short runs, and despite their lack of economy in operation, which must necessarily exist owing to the conditions described, a company has within the past few years been formed for the exclusive manufacture of this style of elevator.

PACKING AND LUBRICATION

Of course, in the manufacture of all the styles of hydraulic elevators here described, a very important feature is the condition of the bore of the cylinders and the external diameters of the plungers. It is absolutely essential that both cylinders and plungers shall be parallel and smooth, any inequalities or inaccuracy causing a waste of the water used in operating them, and one of the most essential features in their care is the proper, and even, setting up of the packing, both in the glands of the plunger machine and in the piston of the cylinder machine.

Many forms of packing have been devised, the earliest being the leather cup, which is almost as old as the hydraulic press, in which latter it proved to be the most successful packing ever devised. In a hydraulic press, the ram or plunger travels a very short distance and very slowly, and under exceeding great pressure, but with the lower pressures used in hydraulic elevators, and with the greater rapidity and distance of travel of the piston, this style of packing was not found to be as long lived as could be desired. Hence, various other means were devised to overcome the defects found to exist in the leather cup. One of the best was that of using a leather cup exactly as the original, but smaller than the diameter of the cylinder by an inch or inch and a quarter, and to fill up the space between the leather cup and the bore of cylinder, rings of ordinary square pump piston packing, made of alternate layers of rubber and canvas, were used. These were held in place by means of a follower ring, and through the web of the piston leading directly behind the leather cup, small holes were drilled which permitted the water in the cylinder under pressure to obtain access behind the leather. This pressure forced the leather outwards against the aforesaid rings of piston packing, pressing them against the bore of the cylinder, and allowing the passage of the piston in a water tight condition.

This form of packing was used very largely in the vertical hydraulics, described above, and introduced by Mr. Baldwin, but this form of elevator had one great disadvantage over the horizontal type of machine, in that both ends of the cylinder were closed, and these conditions did not permit of proper lubrication. Hence, after machines of this type had run a few years the cylinders became badly scored or grooved, and there was a great leakage of water past the piston, and the only remedy was the reboring of the cylinders. In many cases, especially where elevators of this type had been installed where the water pressure was low, the cylinders had been designed with such thin metal in the walls that they would not admit of reboring. In some cases, engineers had tried to introduce a lubricant in the water used to operate the elevators, but with no very marked success.

With the horizontal machines, however, one end of the cylinders being open, lubrication became an easier problem to solve. In these machines, owing to the greater diameter of cylinder, the leather cup and piston packing was not so readily applied, and in lieu thereof, several forms of packing were adopted by different makers, each having his own particular choice. In some cases, plaited hemp was used. Others used the square piston packing made of rubber and canvas before described. Still others used rubber cord; some used it in the square strips and others round with alternate layers of square piston packing, and each of these had its own particular merits and advocates.

The piston had to be made with an annular space for the reception of this packing, so shaped that the pressure of the necessary follower ring, which was essential to the tightening up of the packing, caused it to be forced outwards against the internal sides of the cylinder. This follower ring was made with a roomy groove in that part of it which extended outside beyond the packing, and from this groove extended a pipe leading out beyond the open mouth of the cylinder to the cross head where a large compression grease cup was fastened and kept filled with grease. The tightening of a screw in this grease cup forced the grease through the pipe into the groove in the follower, thereby keeping the cylinder constantly lubricated at every stroke, and to prevent its escape through the open-end of cylinder and consequent waste, a "wiper" or single ring of packing was used with an auxiliary follower ring to tighten it up as required.

There is a peculiarity about the lubrication of the cylinders and plungers of hydraulic elevators not generally known to the persons in charge of these machines, which is that nothing but purely animal oil or grease will give perfect lubrication.

Since the introduction of oils and greases that were partially or wholly composed of products of petroleum, their cheapness and adaptability to revolving shafts and bearings has made them a general favorite, but however well adapted they were for lubrication of this nature, they were wholly unfit where water came in contact with the surface, and that is why they were not suited for hydraulic elevators. Each time the cylinder was filled with water, or when, in the case of the plunger elevators, the plunger became immersed in the cylinder, grease or oil that had been applied during the stroke would float away in the water, leaving the bore of the cylinder or external surface of the plunger entirely bare. To obviate this, it was necessary to use a purely animal oil or grease, which, being a better resistant of water, would remain on the metallic surface for several strokes of the piston or plunger. as the case might be, and consequently was more economical and more satisfactory.

LIMIT VALVES

For limiting the travel of the cage to the upper and lower landings, in other words, to cause the water to be automatically shut off at these points independently of the efforts of the operator, the earlier hydraulic elevators depended entirely on button stops on the operating cable, working in conjunction with a striking arm on the cage.

In all elevators it is the custom, in putting on the operating cable, to arrange it in such a way that pulling down on the standing part of the cable which is used by the operator causes a motion of the elevator in an opposite direction, and vice versa. For instance, were the operator to pull the cable down, the car would rise. Now at a proper place on this cable is fastened a sort of clamp, being made in halves for the greater convenience in putting it on, and the two halves being fastened together with bolts. When put in place on the cable and clamped tightly there, it is immovable except with the cable. An arm of wrought iron is fastened to some convenient part of the cage sufficiently high to be out of the way of the operator, and this arm is formed at one end into a ring which slips freely over the operating cable as the car travels, and strikes the button just described, on arrival at either end of the run, moving the cable exactly as the operator would do it to the central or stop position.

This arrangement worked very nicely and filled all requirements as long as the operating cable was in good condition, but it was found in course of time that, as the operating cable wore or its condition deteriorated from any cause (the principal one being dampness in the pit at lower landing), it was liable to break, and this always occurred when it was least expected, the result being disastrous in every instance. In some cases the piston would come out at the end of the cylinder, allowing the water of the cylinder to escape, causing serious damage, for it would continue to flow through the supply pipe, and at the same time the cage would be run violently into the sheaves at the top of the hatchway, often breaking them and causing other serious damage, and in the case of the plunger elevators, the plunger would come out of the cylinder, allowing the water to escape in like manner.

To prevent this, various expedients were devised, among them being the limit valve. This was an auxiliary valve placed between the operating valve and the cylinder, and was so arranged in the case of the horizontal hydraulic elevator that cams attached to the piston rod at either end—one near the cross head and another near the piston—would engage an arm on a rock shaft, moving the arm so as to cause it to close the limit valve, and thereby prevent the ingress or egress of water to or from the cylinder according as the cage was at the upper or lower limit of its run. The earlier forms of these valves were made single acting, that is to say, they simply closed the pipe between the operating valve and cylinder, and they were so arranged that they did not entirely close it unless the car went a few inches beyond the landing in either direction. When this occurred, the valve had to be opened by hand in order to give the cage headway in the opposite direction, and this was found to be a decided disadvantage.

Then another form of valve was devised of the two-way type, taking water through one passage from the operating valve for hoisting, and discharging it through another from the cylinder through the operating valve also, thus giving the operating valve control of the water at all points, excepting the upper and lower limits of the run. With this arrangement it was possible to run down or up to the extreme limit, allowing the limit valves to take care of the stops at either end, because in this case when the limit valve shut off the supply of water for hoisting at the upper landing, it left the opening for lowering still open and vice versa.

This form of limit valve proved all that was required of it. but even *it* was liable to derangement, so to overcome these difficulties and to make it simply impossible for the elevator to run beyond its limit, more care was taken with having the cylinders of the exact length required for the run, plus the length of the piston, and across the open end of the cylinder and spanning the piston rod, which was allowed to pass freely through it, was a very heavy bar of cast iron, which projected some inches beyond the outer diameter of the cylinder. Similar projections were made on the cylinder head on each side to correspond with the ends of the bar, just described, and running along longitudinally between them were very heavy rods of wrought iron or Bessemer steel threaded at each end. The ends of these rods passed through holes in the lugs cast on the cylinder head and through the ends of this bar, and nuts on the ends of the rods bound the bar and cylinder head together. A rubber bumper was put around the piston rod, clamped there firmly, and set partially in a recess made in the hub of the piston, and upon the arrival of the piston at the end of the run this rubber bumper would come up hard against the heavy bar of cast iron, which being made amply strong for the service it was to perform, prevented the travel of the piston any farther, and in like manner the piston came against the cylinder head of the lower limit of travel, there being a similar bumper of rubber fastened in the recess in the hub of piston on that side. Of course, these cylinder heads had to be strongly re-enforced to withstand the strain, and this was found to answer all requirements, for it would always operate, regardless of whether the limit valve or buttons of the operating cable gave out or not.

In the case of the vertical hydraulics, which were known as the standard elevator, an appliance of this kind was not so easily put on, in fact none was ever devised that acted successfully. The only places they could be used was at the upper end of the run and at the lower end, between the cylinder and operating valve, and this had the disadvantage previously described as existing with the earliest form of limit valve on the horizontal machine. If the valve in the circulating pipe was closed it prevented the elevator from running in either direction; hence, it had to be set so that it would not close entirely, and this very fact impaired its usefulness and effectiveness. In the case of the vertical plunger, however, it was very easily arranged, the cylinder being made so that when the plunger got a little below its lower limit of travel it was made to rest upon the bottom head of the cylinder, and fastened around its lower end was a ring which, when it reached its upper limit of travel, would come in contact with the bottom end of the stuffing box, thereby preventing its ever coming entirely out.

ELECTRIC ELEVATORS

The most popular form of elevator in use to-day is that operated by electricity, and the general arrangement of machines now in use is that of a worm and gear wheel actuated by an electric motor, the gear wheel being attached to a winding drum or spool, the whole machine, of course, being bolted to an appropriate bed plate, and the worm shaft fitted with the proper form of braking apparatus for use in stopping.

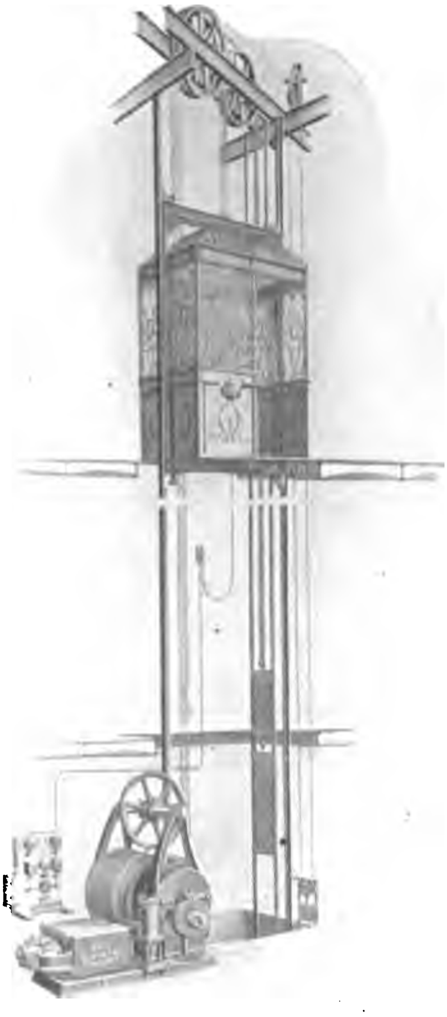
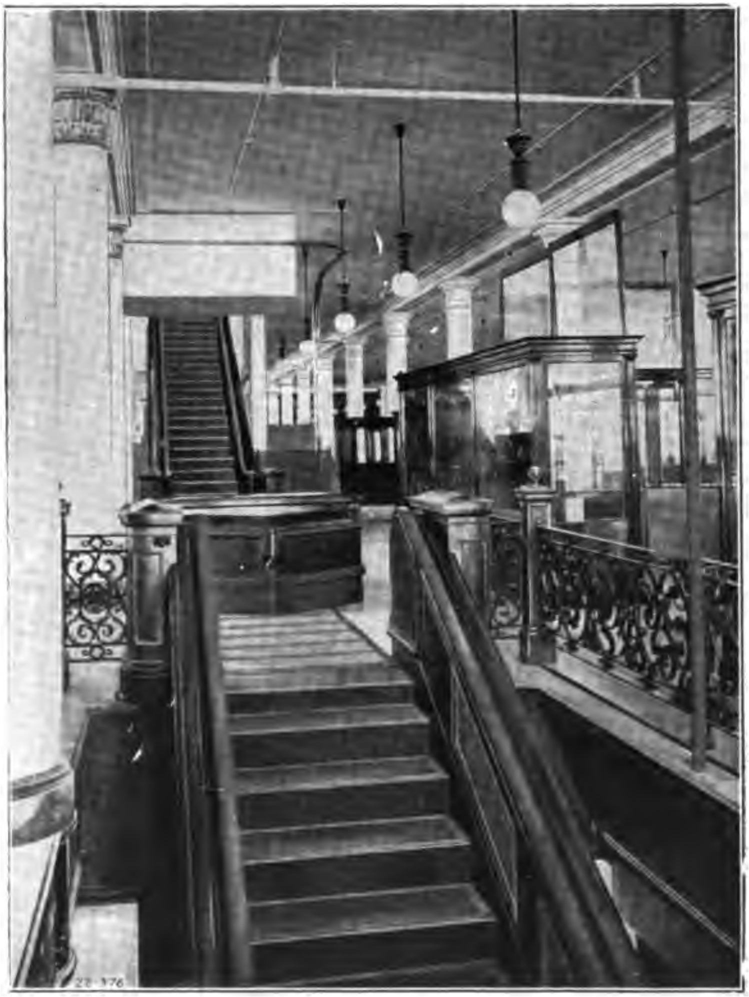


Fig. 11. Electric Elevator.

The motor used for operating an elevator has to differ somewhat from one used in driving ordinary machinery, in that it has to start up from a state of rest with the load on it, and it is a well-known fact that ordinary shunt-wound motors are very weak at starting, hence a modification became necessary. This was discovered very early in the introduction of the electric elevator.

To overcome this difficulty a very strong series field winding is used, and this is usually arranged in two or three sections, and it should furnish fully 30 or 40 per cent of the field excitation. The shunt winding is made proportional to the entire strength of the motor, and when the motor is started, both series and shunt field windings are actuated, and as fast as the motor picks up



ESCALATORS IN A CITY STORE.

sufficient speed, one section after another of the series winding is cut out, leaving the motor entirely on the shunt winding when it has attained normal speed. By this means a regular speed under any load is obtained, the series winding being used simply to give the necessary torque for starting.

The reason the series winding is cut out when the motor attains normal speed is that if left in action the speed of the motor would vary with the load, and this would be more noticeable during a descent of the load than when lifting, for it would accelerate the descent at a rate that would be constantly increasing until the end of the run. By cutting out the series winding and allowing the motor to run on the shunt only, this is avoided. These conditions are brought about by means of the controller.

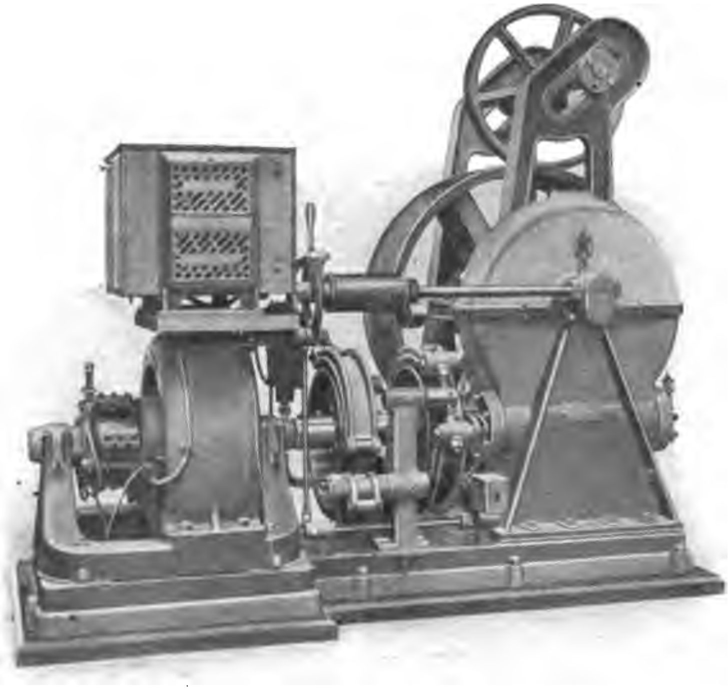


Fig. 12. Direct Connected Electric Winding Engine.

The offices of the controller are varied. It has first to turn the current into the motor through a certain amount of resistance; second, to gradually cut this out in steps as the motor increases in speed. At the same time it must gradually cut out the series winding in sections, and when the elevator is lowering, it also has to take care of the short circuiting of the armature, which will be explained later on. It consists usually of a switch for cutting out or breaking the circuit and for closing it, making suitable connections to the armature leads to cause the motor to run in the direction required. This switch is so arranged that when the circuit is closed, it releases an arm or a cross-head that drops by gravity and thereby cuts out the resistance in steps, doing it by moving the contact piece over a number of plates; the speed of its descent is governed by the escape of air from a dashpot. In some cases, instead of releasing the arm described above, it actuates a solenoid which lifts the arm or cross-head, its speed being governed in the same manner by the use of a dashpot. The breaking of the motor and solenoid circuit is done simultaneously just

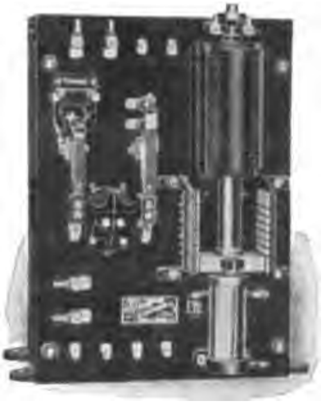


Fig. 13. Controller for Mechanial Operation.

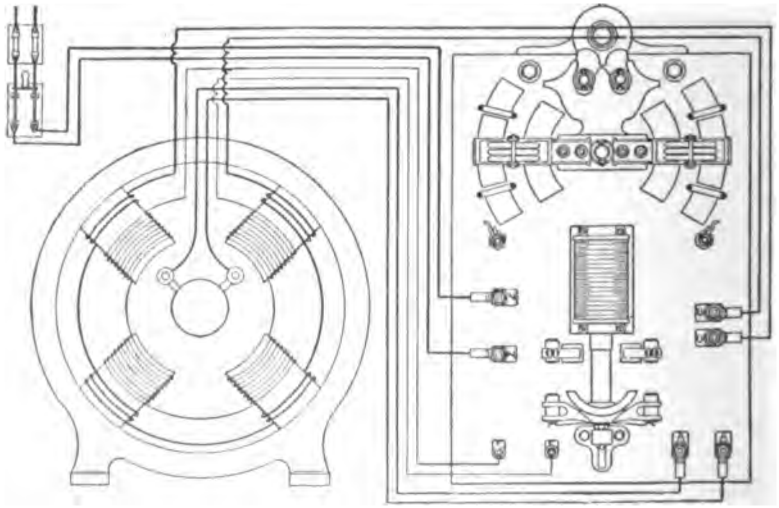


Fig. 14. (A) Wiring Diagram for Mechanical Controller.

prior to the stopping of the elevator, and where the speed of the elevator, or the weight of the loads it carries make it desirable, the controller is so constructed that when the line circuit is broken for stopping, while the elevator is lowering, it cuts in a certain amount of resistance with the armature, causing the E.M.F. in the armature to pass through this resistance, thereby retarding the speed of the motor. This E. M. F. becomes weaker as the speed of the armature decreases, until it finally ceases with the motion of the motor. This method of bringing the elevator motor to a standstill is used in all standard makes of electric elevators to-day, and has been in use since about 1895. In addition to this, a mechanical brake, operated from the rock-shaft of the machine itself, and also a separate mechanical brake, operated electrically by a solenoid, are used. In the case of the latter, the solenoid is so arranged that it releases the brake when the circuit is closed.

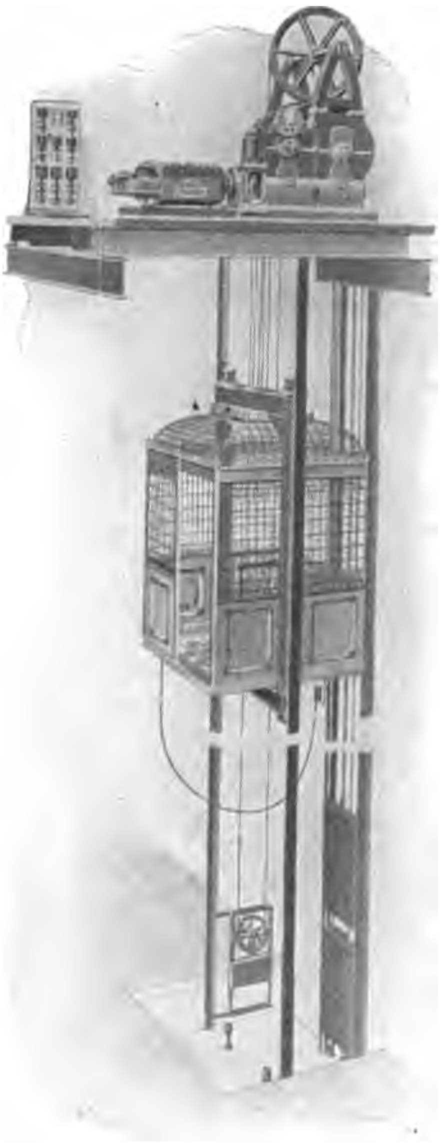


Fig. 15. Electric Elevator with Overhead Driving Mechanism.

This method of stopping and starting, just described, is the one generally used with a mechanical arrangement for operating the elevator; that is to say, with a hand cable or a lever-operating device; the cutting out of the resistance upon the starting of the elevator is purely mechanical. The arm or cross head on the controller, which cuts out the resistance in steps, is made to move over the contact pieces arranged for this purpose, either by gravity or by a solenoid which moves the arm or cross head; for these controllers are made both ways. Some have an arm working at one end upon a pivot, the other end carrying the carbons over the contact pieces; other types have a cross head which ascends or descends according as gravity or the solenoid comes into action. The cross head always has two sets of contacts.

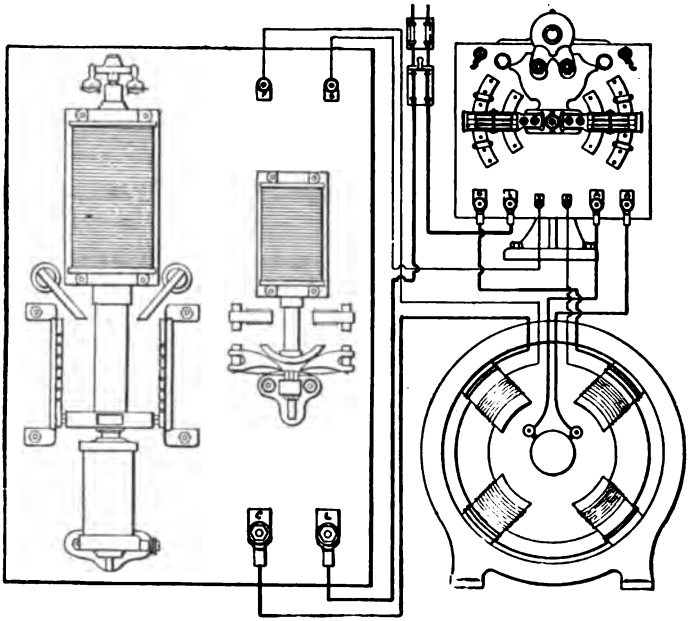


Fig. 16. (B) Wiring Diagram of Controller with Separate Switch.

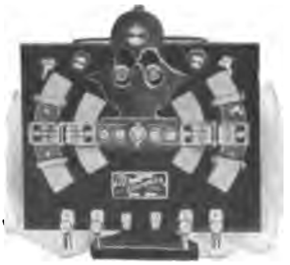


Fig. 17. Circuit Closing Switch.

The time of movement of the arm or cross-head, as the case may be, is governed by the use of a dashpot. The earlier forms of dashpots were filled with a light oil which would flow freely, and the movement of the plunger in the dashpot caused the oil to flow from one end of the cylinder to the other, through a very small opening, which was adjustable as to size. The time in which the arm or cross head passed over the contact plates was thus regulated, but it was found that the oil was affected by temperature, very cold weather making it sluggish and thick, and the action of the arm or cross head correspondingly slow. Sometimes where the oil was of a volatile nature, considerable waste would occur from this and other causes, and then upon closing the circuit the plunger would move very rapidly until it struck the oil and was brought up with quite a shock, and resistance was cut out quickly for two or three steps. This had a bad effect. Sometimes too, the attendant would neglect to replenish the dashpot at all and it would become entirely empty; then the resistance would be cut out so suddenly as to endanger the safety of the motor. To remedy this a dashpot of somewhat larger diameter was used, having a nicely fitting piston, and the air in the dashpot was imprisoned, being allowed to escape through a minute hole at the top or bottom, according to the way the dashpot was placed. The opening being adjustable by means of a screw, the arm or cross head could be made to pass over the contact pieces at any speed desired, the usual time allowed from closing the circuit to attaining full speed being from four to five seconds.

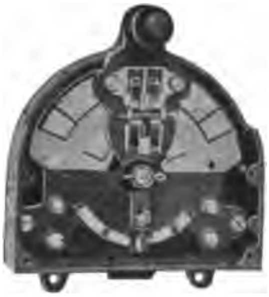


Fig. 18. Electric Operating Switch for Car.

With elevators running at a high rate of speed, however, say 300 feet per minute or more, this method of operation was not as perfect as could be desired; hence, there was devised what is called the electric control. This consists of a small switch located in the cab. From it wires are run in the form of the flexible cable to a point midway of the run of elevator, where the end of the cable is attached to the wall of the shaft, and from that point wires are run to the controller. This cable has to convey but a very small amount of current, simply sufficient to actuate one or more solenoids on the controller. These solenoids operate the switches which make and break the circuit in either direction. The throwing of this switch in the cab to the upright or central position, breaks the circuit always, and moving it either to the right hand or left will close the appropriate switch on the controller to run in the direction desired. This is done by actuating a solenoid on the controller, as before stated, which closes the switch to run the motor in the direction desired. The cable attached to this switch has to have at least three wires, one for the line, and the other two for their respective solenoids, but usually the cables are put in with a number of wires, so that if anything happens to any one of those in use, one of the dead wires can immediately be connected, and thus the necessity for replacing the entire cable is obviated.

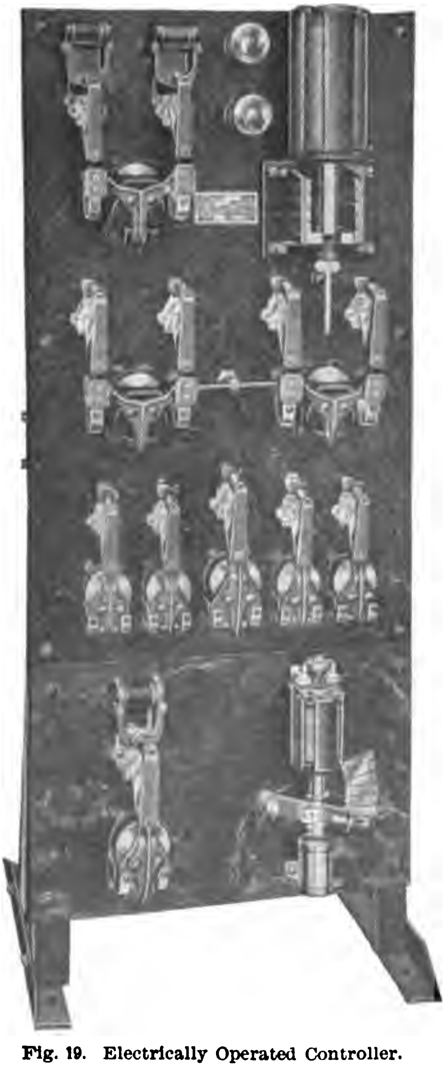


Fig. 19. Electrically Operated Controller.

Controllers of this description operate in various ways; in some, as soon as the line circuit is closed, a solenoid is actuated, which cuts out the resistance in the same manner as described as being used for the lever or hand-cable control. Another form of controller does it in a different manner, which will be described.

The armature is connected with a number of solenoids, each connected with a separate step of the resistance, and so arranged that they require varying amounts of current to actuate them, and the E.M.F. in the armature actuates these solenoids in rotation, the motor being started up at first and running slowly, the E.M.F. in the armature is weak and actuates only the first solenoid, which then cuts out the first step of the resistance. As the speed increases, the E.M.F. becomes stronger and successively cuts, out through the other solenoids, all the resistances as the motor attains full speed. When the circuit is open for stopping the elevator, these solenoids all drop back to their original position and are ready for the next start, and they are used to cut out the resistances in either direction of the motor.

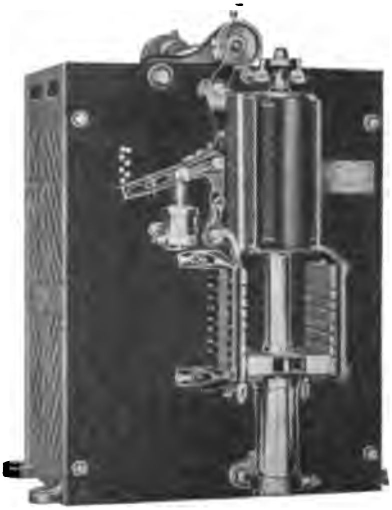


Fig. 20. Mechanical Controller, Variable Speed.

The E.M.F., as before stated, is frequently used as a means of retarding the motion of the elevator when a stop is desired, the most effective method being to introduce a set of resistances in the controller specially designed for the purpose. It is arranged on some elevators so that the E.M.F. actuates a solenoid which applies the brake, the latter being held off by a strong spiral spring. When the circuit is broken, the same movement that opens the switch, connects the armature with this solenoid, and if the elevator is running very fast, the E.M.F. being strong, applies the brake very hard. As the current in the armature, owing to the slowing down of the motor on the application of the brake, becomes weaker, the pressure on the brake becomes less, until finally it ceases entirely, and at this point the other mechanical brake operated by a solenoid, whose office is only to release it, is applied permanently by mechanical means. With this arrangement, one solenoid slows the motor and brings it to a stop, and having attained that point, the other solenoid releases its hold on the brake and allows the spring to apply it.

This latter arrangement, however, of using the E.M.F. to apply the brake, is simply a roundabout way of reaching the result—partly by mechanical and partly by electrical means—and is not really necessary; the short circuiting of the armature through resistances in the controller is all that can be desired.

In many elevators where a variable speed is desired, connection is made between the armature and a solenoid connected to a switch which is kept closed except when the solenoid is actuated. This switch closes a circuit between the shunt field coils and a bank of resistances in the controller, specially designed for the purpose, and has the effect of weakening the fields. This causes the motor to run at a greater than its normal speed, so that with a light load where the E.M.F. in the armature is not great, the elevator will always start up and run much faster than when a full load, or one nearly approaching it, is in the cage; for when the greater load has to be lifted, the E.M.F. in the armature becomes strong enough to actuate the solenoid, which opens the switch, thereby cutting out the resistance in the fields and leaving them stronger, and the speed of the motor immediately becomes slower. This is a very

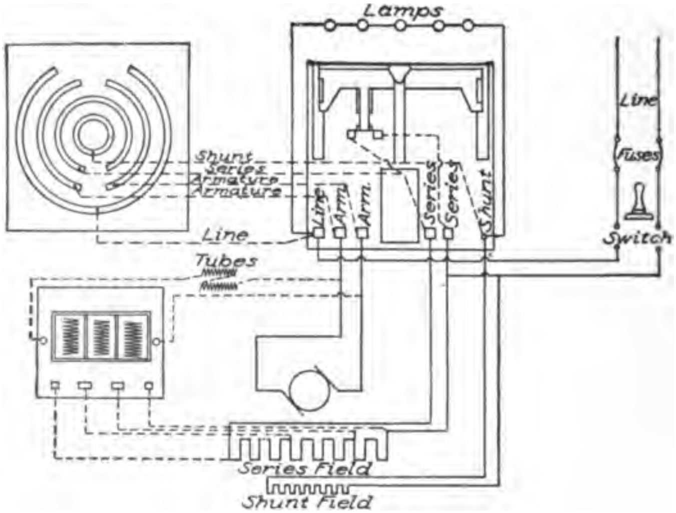


Fig. 21. (C) Wiring Diagram for Mechanical Controller.

nice device and does its work automatically and is quite reliable.

The idea of weakening or strengthening the fields of a motor to gain or lessen speed is almost as old as the first electric elevators, but where current is taken from a public supply, or where only one elevator is used, it is usually not practicable to deviate from the methods above described. The ideal electric elevator, however, is one where a separate dynamo is used for supplying the fields and one for the armature. A field regulator connected with the dynamo supplying the fields can be placed in the cab, by means of which the operator can weaken or strengthen the fields of the dynamo supplying the current to the fields of the armature driving the motor. By this means a great variation in speed may be had. But while fairly economical in its operation, it is a plant that is expensive to install, and though it has been done in a few instances, there are not many of this type of elevator in existence.

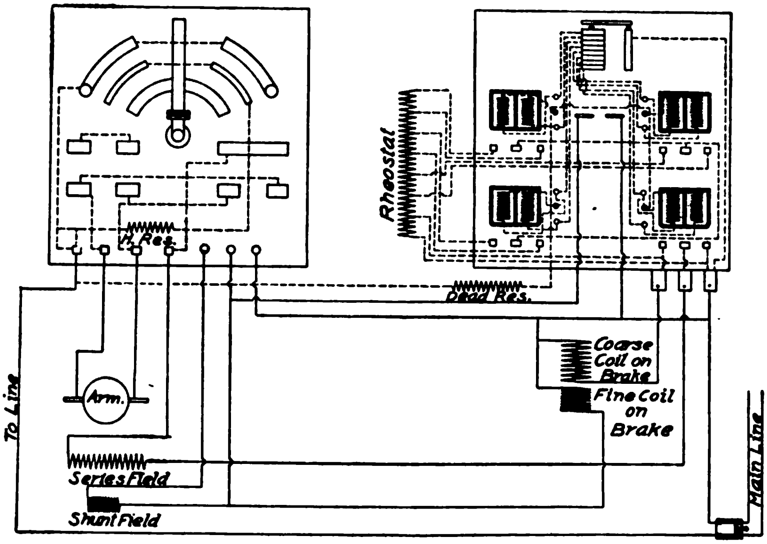


Fig. 22. (D) Wiring Diagram of Controller with Solenoid Cut-outs.

ELECTRIC LIMIT SWITCHES

It was found in operating electric elevators that more space was needed between the cab and the overhead sheaves at the upper part of the run, and that a deeper pit was also required at the bottom of the run on account of the occasional slip of the brake.

For frequently, although the mechanical, automatic or limit stop on the machine would break the circuit and apply the brake near the end of the trip, there were cases—for instance when the empty cage was required to ascend at full speed and the brake had become slightly worn and did not grip as firmly as usual—that the cage would go beyond the landing, and the additional space mentioned above was required to prevent a collision. This also happened sometimes at the lower end of the run when an extra heavy load was descending. A lack of care on the part of the operator in breaking the circuit in sufficient time, or the causes just mentioned, would cause the cage to run down to the bottom and bump. To avoid this, as an extra measure of safety, switches are sometimes placed at the extreme limit of the run, the line wire being carried up the hatchway through the switch and returned.

These switches are opened by the car automatically if it should pass a certain point, and the opening of this switch breaks the circuit and at the same time applies an extra strong emergency brake. The switches are operated by means of cams attached to the cage.

MISCELLANEOUS ELECTRIC ELEVATORS

There are one or two other types of elevators that have been more experimental than practical in their nature, which will be mentioned here. One of them, the Pratt-Sprague, consists of a long screw running horizontally in bearings at either end, which is driven directly by a motor placed at one end. The screw runs in a nut having a cross head, which travels on guides horizontally, the same as the cross head of a horizontal hydraulic, and is supplied with sheaves on either end. The construction of the machine is such that a double set of traveling sheaves and also fixed sheaves is necessary. The cables are rove over these sheaves similar to the method described for the horizontal hydraulic, and the motor, of course, is reversible.

One of the principal features of this type of machine was the construction of the nut which traveled on this large screw. It was supplied with steel balls on the pull side of the screw, and they ran close together in single file through a channel, which carried them around through the threads of the nut and caused them to return to the other end of the same after they had passed through. Of course, there had to be so many of them that they completely filled the channel from one end to the other, and it was thought that their use would reduce the friction to a minimum. It was found, however, in practice that they would get flat spots on them and cease revolving, and where they did this they would cut grooves or scores in the thread of the screw, which latter was a serious matter. They are very prone also to become deranged, and their operation was not as economical as had been anticipated.

Very few of these elevators are in use at the present time. The controlling device, however, was quite novel and the operation of the cage very agreeable and pleasant. The control of the motor driving this screw was effected by means of a small pilot motor operated in turn by means of push buttons in the cage.

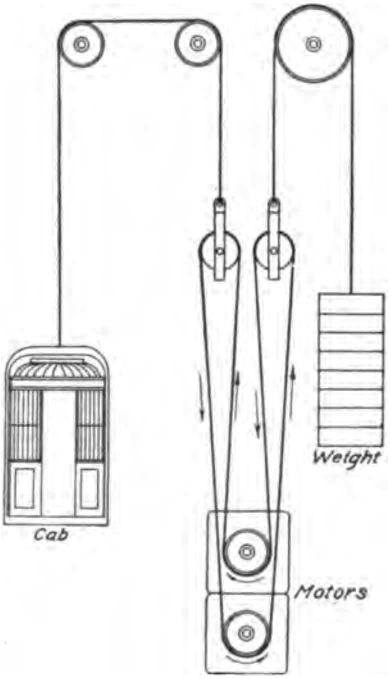


Fig. 23. Diagram of Fraser Elevator.

Another type of elevator was that devised by Mr. Fraser, of California, the driving mechanism of which consisted of two motors set one above the other. They were necessarily slow speed motors, and each one had upon the armature shaft sheaves of about 20 inches diameter. The motors themselves ran at a speed of about 420 r.p.m., and the cables were so arranged as to form a double bight or loop below, in each of which one of these pulleys on the armature shaft ran as shown in the accompanying illustration. The upper ropes of the cables had sheaves carrying them and running in a frame, to one of which was attached the car cable, and to the other the counterpoise cables. These motors ran in opposite directions, and in the cab were placed rheostats for weakening or strengthening the fields. By this means the speeds of the motors could be varied. By reference to the diagram illustrating this description, it can readily be seen that when both motors were running at the same speed, no motion of the car was obtained, but by varying the speed of either motor the car would run at a speed equal to half the difference of the two motors. No reversing apparatus was needed with these motors; they ran continuously in one direction, the motion of the car being gotten entirely by the change in speed, and the most desirable stops and starts were obtained. But the machine was very severe on the cables, so destructive in fact that they had to be renewed frequently; and taking it altogether, it was not found as desirable a machine as had been anticipated, either from the point of economy or maintenance, but results in operation were all that could be desired, including the speed attained and smoothness of stops and starts.

ELEVATOR ACCESSORIES

An elevator is really a vertical railway, but differs from one running on horizontal rails in that it does not use wheels, but slides on its track, and in order to avoid friction as much as possible, the cage should be hung centrally. The rails used for the cage to travel on are, in the more common types, usually of wood, hard maple being the material mostly adopted, and it is kept constantly lubricated with some form of grease. The guide ways after some weeks' use become rough and dry from various causes, principally from the rubbing off or evaporation of some of the component parts of the grease, and also from the accumulation of dust, which sticks readily to the lubricant. They then have to be cleaned off and relubricated, the object being of course to keep them as smooth and free from friction as possible.

Great care has to be taken when installing them to have them in perfect alignment and the joints very even; and maple, being a wood that is prone to warp, has to be put on in short pieces, the usual lengths being about four feet. The ends of these guides are tongued and grooved to fit into one another, and where the guide posts, to which they are attached, are made of wood, they are fastened thereto by means of appropriate lag screws, the ends of which are recessed into the face of the guides. The shoes on the cage which run on these guides are usually machined to fit, and are made as smooth as possible at their faces of contact.

The device generally used for stopping the cage in case of a sudden descent, caused either by the breakage of the cables to which the car is suspended or by the derangement of any part of the machinery, is a pair of dogs, one placed in each guide-shoe beneath the car on opposite sides. These dogs are in the form of an eccentric, the outer face of which is supplied with coarse teeth, which, when the dog is revolved on its axis, come in contact with the guide strips; and as these teeth enter it, the descent of the car causes a further partial revolution of the dogs, so that the guides become tighter and tighter as the car descends, and bring it to a stop. This operation takes much less time to occur than it does to describe it here, the fact being that after the dogs begin to catch, the car descends but a very few inches before it is brought to a dead stop.

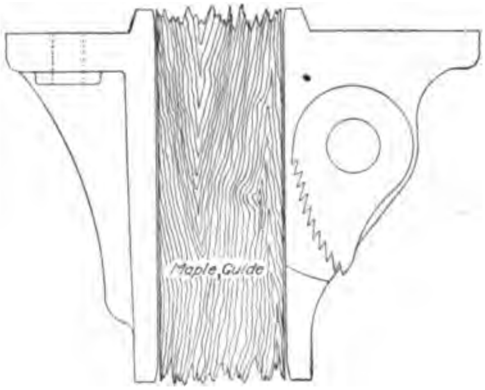


Fig. 24. Eccentric Safety Dog.

These dogs were originally used in connection with a spring for throwing them; hence when they acted at all they acted very quickly and before the platform had gained much headway, and while this was quite satisfactory in a slow running elevator, it was found to be quite objectionable with elevators of high speed—the sudden stopping producing a severe shock to the occupants of the cage—and moreover there were many cases where the elevator would descend rapidly, and the dogs failed to act, because they depended on the severing of the hoist cables for their action. They were operated by a spring which, being held in tension by the weight of the cage on the hoisting cable, would never act while that tension existed. Hence, if the cables were to break at or near the drum of the machine—the machine being located in the basement—these cables had to pass from the drum up and over sheaves at the top of the hatchway and it would require considerable power to drag them over these sheaves. This would be sufficient in itself to hold the spring out of action.

With the introduction of the safety governor, however, this trouble disappeared. The governor is a revolving sheave having within its rim dogs or arms set upon pivots and held in place by means of strong springs, either spiral or flat. These springs are so adjusted that the normal speed of the elevator does not affect either them or the dogs, but should the speed of the elevator exceed the normal by about 25 per cent, the centrifugal force exerted by these dogs, which are weighted somewhat, will overcome the tension of the springs, and they will fly out beyond the rim of the sheave, catching on a stand in which the sheave runs and stopping its revolutions entirely.

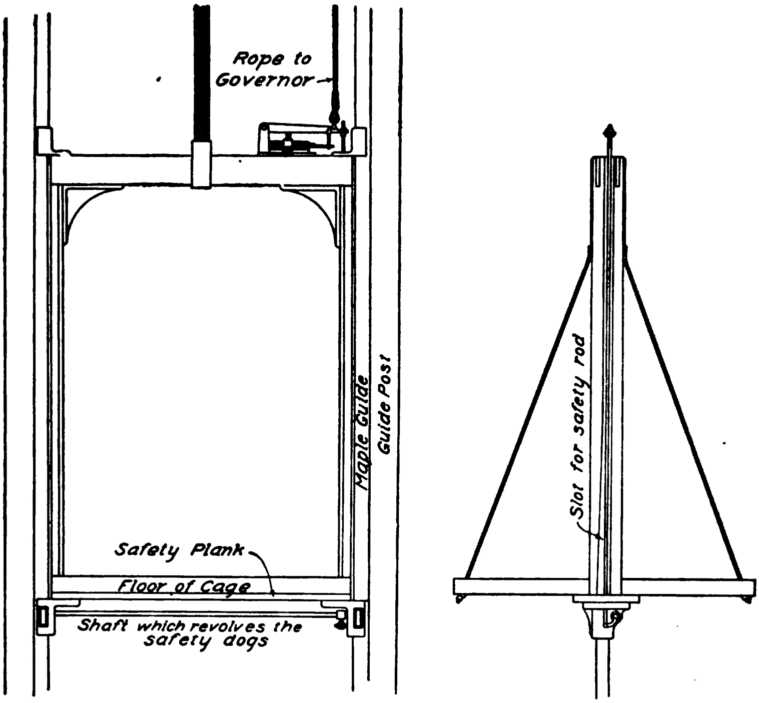


Fig. 25. Arrangement for Throwing Safety Dogs.

Now this sheave has a V-shaped groove in which runs a manila rope about $\frac{3}{4}$ inch in diameter. One end of this rope is made fast to a lever on the top of the cage, which operates the safety dogs, the other end is carried down the hatchway and around another sheave at the bottom and back again up to the cage, where it is attached at some convenient point, usually to an arm placed on the stile for that purpose. This sheave, which runs in the bight of the governor rope, is in a frame, which runs on guides and has a moderately heavy weight attached below it which serves the double purpose of keeping the governor rope taut and of taking up or compensating for the stretch of the rope. It also gives the necessary tension for driving the governor, and when the sheave in its revolutions throws out the dogs and stops itself, as before described, the V groove in the sheave grips the governor rope tightly and thereby pulls on the safety lever on the cage and throws in the safety dogs. It can be readily seen that with an appliance of this kind, the cage would have to descend quite a

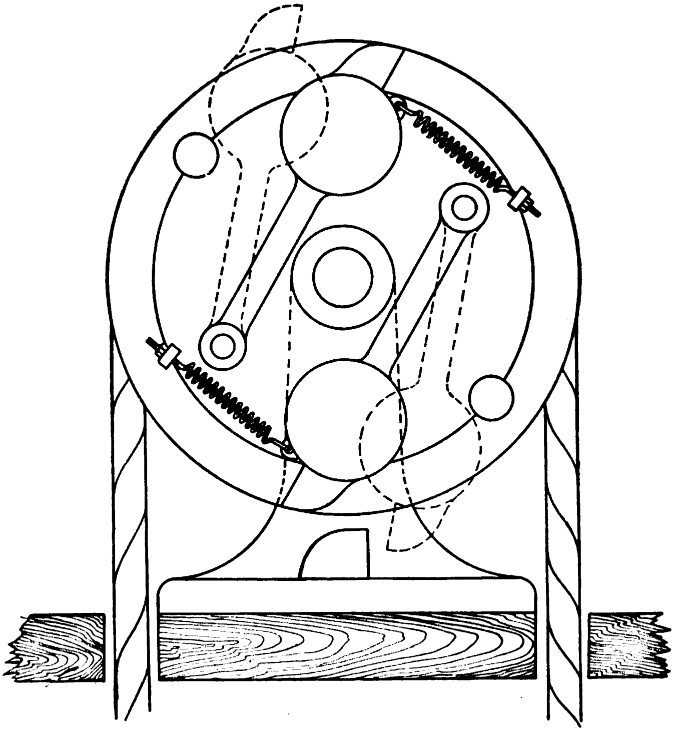


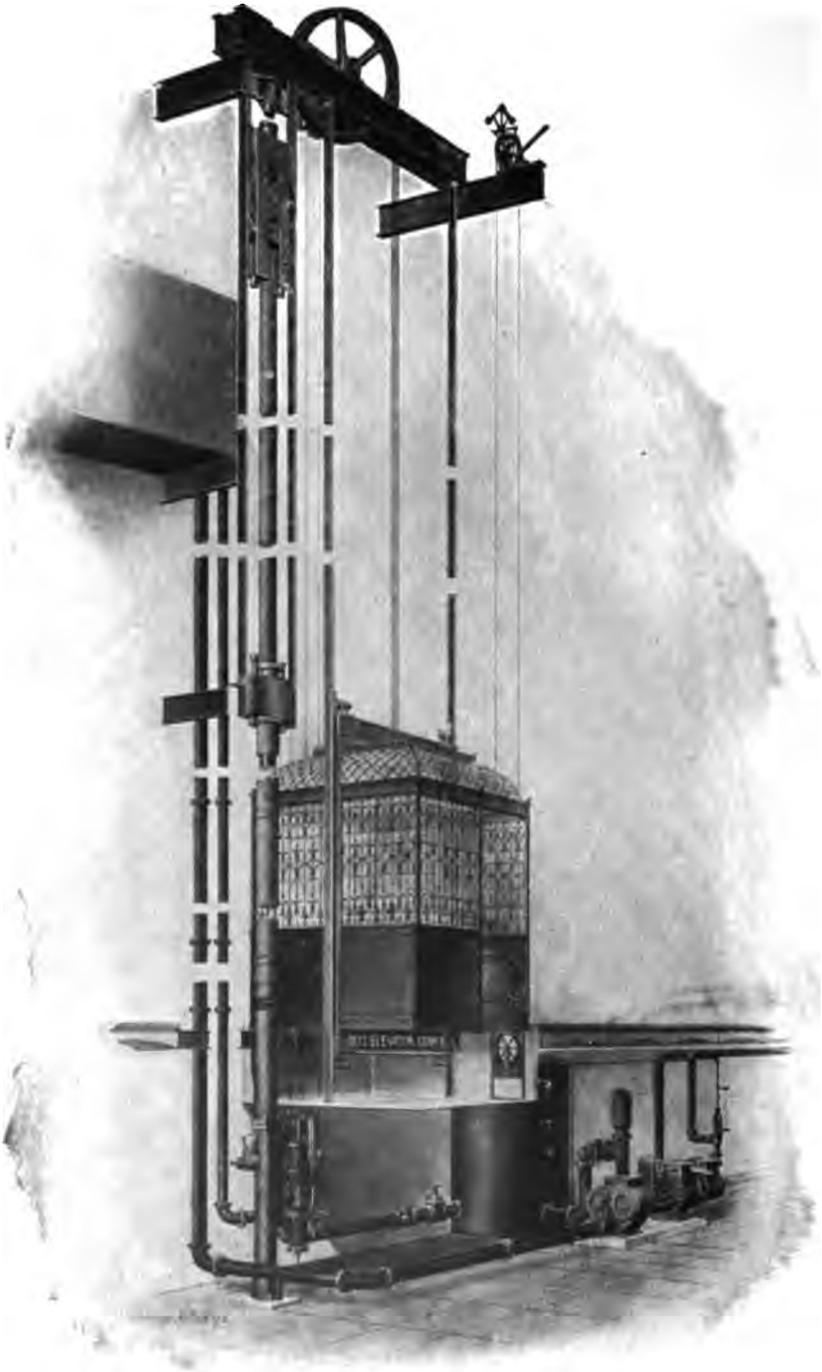
Fig. 26. Diagram of Safety Governor

distance before its speed would increase sufficiently beyond the normal to actuate the governor, and for this reason the style of safety dog described above, which was the first form introduced, was very objectionable, on account of its sudden stopping of the cage at the high speed it had attained by the time the dogs were thrown in. Therefore a modification of it was introduced in the form of a chisel, which, instead of catching into the guide strip as suddenly as the eccentric dog, would plane it out for quite a length, only entering deeper after the car had descended some little distance and thereby bringing the cage to a more gradual stop.

The form of safety governor described above is the one now in general use; the earliest form, however, differed slightly from it, being a governor having arms with balls on the ends, and revolving horizontally. The same method of driving it, however, was used, except that this governor was placed on the cross beam of the cage and threw the safety directly itself.

A still earlier form of this type of governor was used at the top of the hatchway, many years ago, but not driven by a rope. In the case here referred to, drums were used at the top of the hatchway, and separate cables from the hoisting engine were run directly to the drum overhead, terminating there. Other cables were run from that drum down to the cage, so that there was a constant winding of one set of cables on the drum and unwinding of the others, according to the direction the elevator was going. This drum had on its axis a gear wheel, which drove the governor, and the governor, in that case released a very heavy weight placed on the end of the lever. The dropping of the weight applied a powerful brake to the rim of the drum. This style of governor is not much used at the present time.

With the introduction of higher speeds in elevators a guide post and guide combined in one, and made entirely of steel, was devised and used, and it is in use to-day with all the high-class elevators; but its introduction, while giving greater smoothness of operation and offering many advantages that the wooden guide did not possess (that of remaining in alignment and consequently giving smoother action being the principal one), caused the necessity for a different form of safety than the eccentric or chisel dogs,



PULLING PLUNGER HYDRAULIC PASSENGER ELEVATOR.

before described, which were not applicable to this form of guide, hence a new device had to be introduced. This was in the form of a powerful pair of nippers placed below the car, one on each side. The inner ends of these nippers on being forced outward, caused the jaws of same to grip the steel guides with tremendous force, but the means of applying them being gradual they did not stop the cage suddenly but allowed it to slide several feet, bringing it gradually to a stand.

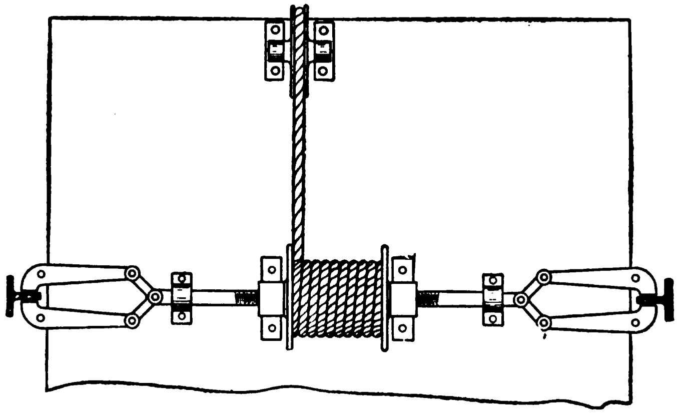


Fig. 27. Safeties for Steel Guides.

The form of governor used to actuate these safeties is similar to that described above. The pulling of the governor rope causes the release of a very powerful coil spring under the car, which forces the dogs into action. There are several forms of this device, none of them differing materially, except in the method of applying the power to grip the guides, one or two of them dispensing with the coil spring, before mentioned, and using a powerful screw and knee joint. The screw is operated by the end of the governor rope, which is coiled several times around a spool or barrel on the body of the screw. The governor rope is gripped by the governor, and the descent of the car uncoils the governor rope off the spool, which is made to revolve, and, being attached to the screw, causes it to revolve. This action causes the knee joints to force the long end of the nippers apart, the short ends gripping the guides powerfully.

Another point in which the elevator differs from the horizontal railway is that in moving a load on an elevator the force of gravity has to be overcome as well as that of inertia. Hence, it is found to be economical to counterbalance the cage, and for that reason slides very similar to those on which the cage travels, but lighter in construction, have to be provided, in which a counterpoise weight travels. Sometimes more than one of these counterbalance weights are used, in some cases running in separate slides, in others, varying with the conditions, with each weight having a slide to itself.

When a counterbalance weight is used, which is attached directly to the cage, it can never be as heavy as the empty cage by several hundred pounds, depending largely upon the height of the building and the number of cables attached, for when the cage is at the top of the run, these cables hang over on the opposite side of the sheaves and have the effect of further counterbalancing the cage. The weight of the cage itself must therefore be greater than the combined weight of these cables and the counterbalance weight, otherwise, the cage would not descend when empty. When it becomes necessary to have the counterbalance weight fully as heavy as the empty cage, or, as occurs in many instances, it is required to be greater than the cage, this counterbalance weight has to be attached by means of cables running over sheaves at the top of hatchway to the opposite or back side of the hoisting drum. Where a cage is large and consequently quite heavy, the attaching of a counterpoise to the cage itself, as well as to the rear side of the hoisting drums, is done as a means of relieving the hoisting cables of a part of the weight they have to carry, and this adds to their durability and safety.

In the case of the electric elevator the over-counterbalancing of the cage is found to be quite economical in this way. An estimate is made of the average load which the elevator has to lift in its daily service, and it is over-counterbalanced to about this amount, the result being that, with the average load, the only power to be exerted in moving it will be that necessary on account of the friction of the machinery. For instance, it may be estimated that the average load of the elevator will be 500 or 600 pounds, although it is built to lift say 2,000 pounds. If it is overweighted this amount, it will be on a balance with the average load, and the amount of power required to move it will be a minimum.

This arrangement is found to give very good results as to economy in operation, but of course in order to get the very best results the cage should be built as light as possible commensurate with the requisite strength and stability; for if the cage is made unnecessarily heavy and it has to be counterbalanced equivalent to its weight, there is that much heavier body of material to start and stop each time the elevator is operated, and there is that much greater inertia to overcome, which consumes power. The necessity, therefore, of building everything as light as possible will be readily seen.

Where two counterbalance weights are used running in one slide, it should be an invariable rule to place the heavier weight, which is always that one attached to the rear side of hoisting drum, below the one attached directly to the cage, for there is a liability at times of counterbalance weight cables breaking, the same as there is with hoisting cables. Should this occur with the drum or heavier weight above the cage weight, the consequences would be disastrous, for combined they would weigh considerably more than the cage, and in falling would rush it upwards to the top of the hatchway at a great speed, provided of course that the cables by which the car weight was attached did not give way. Where the cables of the lower weight pass the upper weight, the latter is usually slotted throughout its whole length to allow their passage.

The best form of counterbalance weights used at the present time in elevators is made in sections so as to be readily changed or adjusted when desired. They consist of a head and bottom weight, which are usually provided with suitable guide shoes to run on the slides, and between them are shorter weights, which do not touch the guide, and which are called subweights. The whole number of weights are held together by means of strong iron rods with double nuts at either end. These pass through holes cast in the upper and lower sections of the weight, and the intermediate or subweights are held in position on these rods by means of grooves in their ends, which fit over the rods, the whole being clamped together firmly by means of the nuts just mentioned.

Sometimes, where the counterbalance weight is necessarily very long, a middle weight with guides on it is inserted, through which the rods holding in the subweights pass, thus giving it greater rigidity and safety.

A very important part of the elevator is the overhead sheaves and bearings. In the earlier forms of elevators, these bearings were set on wooden beams overhead, passing across the hatchway in the proper direction to let the cables drop where required. In later years, however, general practice seems to lean to the use of steel I-beams for this purpose, and they are certainly much safer in case of a fire occurring in the building. It frequently happens in case of a fire that the elevator is one of the principal means for getting people out of the building, and where these beams are of steel there is no doubt as to their greater safety under such conditions. The sheaves should always be as large as can possibly be used under the circumstances,—never less in diameter than the drum around which the cables wind—and the rule usually adopted is that the sheave should be at least 40 times the diameter of the cable which is to run over it, and as much larger than that as the conditions will permit. It is also very important that the score of these sheaves should fit the cable very well, otherwise, with heavy loads the latter becomes distorted, and even under the best conditions the wear of the cable will be rapid unless lubricated. For this purpose, there is nothing better than raw linseed oil applied with a brush, and it is very much improved in usefulness if a small quantity of the finer quality of plumbago be mixed with it. This material when unrefined is full of grit, and is put on the market in this condition for use as facing for moldings in foundries. It is very essential that this kind be not used, for the presence of the grit will have exactly the oppposite effect to that intended. After the plumbago has been carefully freed of all the grit it contains, it is a very good lubricant and in this condition it is very serviceable, both for the purpose just described and, in connection with grease, for the slides.

CABLES

Should the wires of the cables used in hoisting be run perfectly parallel to one another, they would not only last longer but they could be subjected with safety to a much greater strain, but that is found to be impracticable with running ropes, hence they have to be twisted, first in strands of 19 wires each, then six of these strands are twisted together around a center or heart made of hemp. The object of this arrangement is that in working over the sheaves the wires may rub on something softer than themselves and not abraid, for the parts of a hoisting cable when in use undergo many changes in position. For instance, when passing up the hatchway, the parts remain normal or as they were when made up, but when they come to the sheave the strands necessarily change positions slightly, being bent in a circle, and after passing over the sheave and down on the other side they change again to nearly the original position. As they are twisted around one another, different parts of the same cable change their relative positions quite frequently, for their very shape—being spirally wound around one another—causes them to roll slightly in the grooves of the sheave, and they do not always fall into exactly the same position when they return. Hence, the absolute necessity for some sort of lubrication. This change of position or twisting of the cables has made it advisable in cases where a large number of cables are used together (say for instance four or six cables running over one sheave) to use them alternately of right and left hand lay, the meaning of which is that some cables are twisted right-handed and others left-handed, and by using them alternately in this way they serve to correct the action of each other and prevent many minor troubles that will occur when laid up alike.

The scope of this article will not permit going into details relative to the proper fastening of the cables, which is a very important feature, but which is really in the hands of the elevator constructor, and with which the attendant has little to do.

The journals of the gudgeons or shafts upon which the sheaves revolve should always be of soft strong steel and of ample diameter, and the boxes in which they run should be lined with a very good quality of babbitt, and should be provided with good lubricating facilities. They are parts of the elevator that are neglected perhaps more than any other. Being at the highest point and out of the way, they are very seldom noticed, but at th same time too much emphasis cannot be placed upon the absolute necessity for properly attending to this important feature of the machine.

The operating cable, owing to the impossibility of following the rule laid down for the hoist cables regarding the diameters of sheaves, is usual to make of a much finer wire, and the number of wires to a strand is also greater. It is usually that kind of wire rope which is termed tiller rope, and is soft and flexible. The diameter is almost invariably ½ inch, except in cases where the lever device is used, when the necessity for a rope of that size does not exist. The ½-inch diameter is used principally because it is convenient for the hand, and it is seldom that a larger sheave than 12 inches is found practicable, but in any case, whether for hand cables or hoisting cables, iron ropes should always be used. It is true that a steel rope has a greater tensile strength, but the bending over the sheaves causes it to crystallize much more rapidly than an iron rope does, and it will consequently commence to crack sooner. The very best iron for this purpose is either Swedish or charcoal iron, which are very nearly pure, exceedingly ductile, and will stand the bending and straightening for a much greater length of time than a steel rope.

Wire cables have, in some instances, been known to run without fracture for eight, ten, and even twelve years, but there are very few in constant use that last more than three or four years. Some do not last longer than two years where subjected to constant and severe service, and in any case they should, on general principles, even if showing no outward signs of deterioration, be changed for new ones at the end of five years, under the most favorable circumstances. Cracking occurs very gradually and can readily be detected long before it actually occurs by the exterior appearance of the rope, but there are many cases where ropes crack inside before they do on the outside, and this can only be discovered by getting the rope entirely slack and slightly untwisting it so that an examination of the interior can be made. Holding one's hand gently on the rope while it is running will frequently detect a cracked wire if it be on the outside, but an examination of this kind must be carefully made to be of any service.

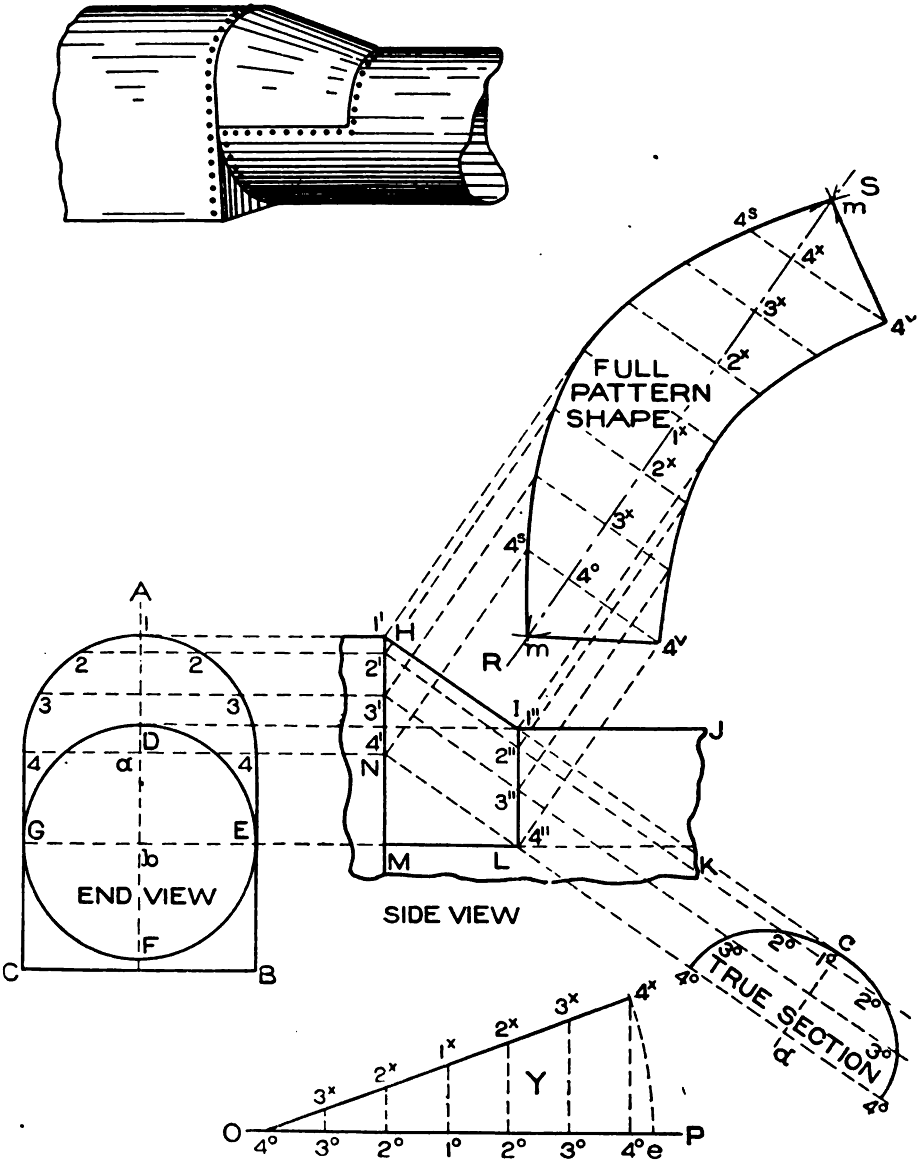
In regard to sheaves, sometimes an arm will crack through an undue shrinkage strain brought about possibly in some cases by disproportion in the design, or by unequal cooling in the foundry. In such cases the crack usually opens quite wide, but where it occurs from undue shock or jar, the fracture may occur and remain closed, so that it is not detected. Still the sheave is unsafe. Usually this can be perceived by care on the part of those in charge, for when the arm containing the fracture is in such a position that it is not subjected to the strain of the cable running over it, the crack, however minute, will open slightly, and it is liable to absorb or take in a minute portion of the oil which is generally on the sheave and which runs down from the journal boxes. This arm when it comes around to that point where it is subjected to compressive strain will force the oil out of the fracture in the form of a small line projecting above the surface of the sheave. It requires a sharp eye to detect this, but it can be seen with care, and many a possible accident has been avoided by the acuteness of the attendant in this respect. It is here mentioned for the benefit of those readers who may be in charge of elevators.

AIR CUSHIONS

About 1878 Mr. Gray, of Cincinnati, conceived the idea of an air cushion as an extra means of safety for elevators, and obtained the first patent for a device of this kind. The air cushion consists of an extension of the hatchway below the lower landing, and is in the form of a strongly enclosed air-tight chamber open only into the hatchway above. The guide posts are run down into this hatchway and the cage is made to fit it rather closely. This is usually done by fastening strips of thick rubber or leather below the floor of the cage, and allowing them to project to within about ½ inch of the sides of the air cushion. Now in case the cage should break loose from the cables, it will descend until, having entered this chamber a certain distance, the air contained within the chamber is compressed sufficiently to resist the further descent of the cage. At this point it begins to escape through the margin left all around the sides and the speed of the cage's descent is retarded until it sinks gradually to the bottom of the chamber without shock or jar.

The margin all around the cage for the escaping of air is a very essential feature to the success of this device. Many errors were made in some of the earlier forms of this device, owing to this feature not being well understood, for it is quite possible, where the air is confined too closely, to stop the cage violently; in fact, this will be the effect if the air is not allowed to escape. On the other hand, if too wide a margin is left, the effect desired will not result. Great care has to be exercised to have the chamber forming the air cushion air tight, strong enough to resist the strains that will be brought to bear upon it, deep enough to enable the car to come to a stop gradually, and to have the air space around the car just right to allow the air to escape in sufficient quantity to prevent a shock, and at the same time not fast enough to allow the car to drop too quickly after it enters.

The usual depth of the air cushion is about 8 or 9 feet and the space or margin left between the cage and sides of air cushion is from $\frac{3}{8}$ to $\frac{1}{2}$ inch. Some modifications are usually made after the work is finished by dropping the cage from a moderate height and noting results, before allowing it to drop the full extent of the run. This is an experiment that should not be performed by inexperienced persons, for accidents have frequently happened even to men thoroughly experienced in the business.



PATTERN FOR GUSSET SHEET OF BOILER, SHOWING DEVELOPMENT.

SHEET-METAL WORK.

PART I.

The sheet-metal worker of today who wishes to succeed must know far more than was necessary years ago. There are many good, practical sheet-metal workers in the trade who are handicapped because they are unable to lay out the patterns that arise in their daily work. Notwithstanding the introduction of labor-saving machinery, the demand for good workmen has increased. While most sheet-metal workers acquire practical knowledge in the shop, they lack the technical education necessary to enable them to become proficient as pattern cutters and draftsmen. In this course, special attention is given to the fundamental principles that underlie the art and science of pattern drafting.

Practical workshop problems will be presented, such as arise in everyday practice, thus giving the student the practical experience that usually comes only after long association with the trade.

CONSTRUCTION.

In constructing the various articles made from sheet metal, various gauges or thicknesses of metal are used. For all gauges from No. 20 to No. 30 inclusive, we assume in the development of the pattern, that we are dealing with no thickness, and we make no allowance for bending or rolling in the machine. But where the metal is of heavier gauge than No. 20, allowance must be made for shrinkage of the metal in the bending and rolling operations, which will be explained in connection with development in heavy sheet-metal work. What has been said about wiring, seaming, and transferring patterns in the Tinsmith's Course is applicable to this course also. It is sometimes the case that the capacity of a vessel or article must be determined, when the rules given in Mensuration should be followed. When figuring on sheet-metal work, the specifications sometimes call for various metals, such as galvanized sheet iron or steel, planished iron, heavy boiler plate, band iron, square or round rods for bracing, etc., zinc, copper, or brass; and the weight of the metal must often be calculated together with that of stiffening rods, braces, etc. On this account it is necessary to have tables which can be consulted for the various weights.

TABLES.

There is a wide difference between gauges in use, which is very annoying to those who use sheet metal rolled by different firms according to the various gauges adopted. It would be well to do away with gauge numbers, and use the micrometer caliper shown in Fig. 1, which determines the thickness of the metal by the decimal or fractional parts of an inch.

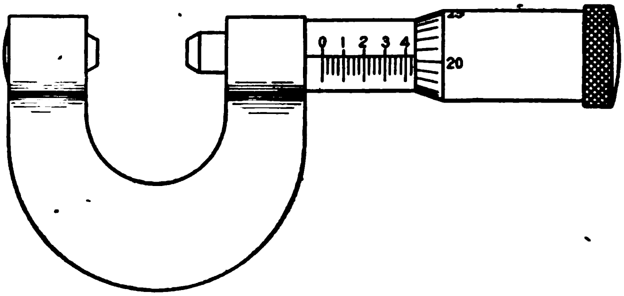


Fig. 1.

This is the most satisfactory method for the average mechanic who works sheet metal manufactured by firms using different gauges. The tables on pages 61 to 74 can be consulted when occasion arises.

SHOP TOOLS.

In allowing edges for seaming and wiring, we must bear in mind that when a seam is to be grooved by hand or machine the allowance to be made to the pattern should conform to the rolls in the machine or the hand tools in use. The edges of the pattern are usually bent on the sheet-iron folder, or brake, while the seam can be seamed or grooved with the hand groover or giant grooving machine. Where round pipe work is done in lengths up to 3 feet, the slip roll former is used, while square or rectangular pipes are bent up on the brake in 8-foot lengths. Where pipes, elbows, stove bodies, furnace shells, metal drums, etc., are made, the sheets are cut square on the large squaring shears, rolled, grooved, and stiffened, by beading both ends in the beading machine, using ogee rolls. There is also a special machine for seaming the cross seams in furnace pipes, also a set of machines for the manufacture of elbows used in sheet-metal work. As before mentioned, if these machines are at hand, it will be well to make slight modifications in the patterns so that both the machines and patterns may work to advantage.

PATTERNS OBTAINED BY VARIOUS METHODS.

In this course will be explained the four methods used in developing patterns for sheet-metal work, namely, parallel line, radial line, triangulation, and approximate developments. What was said on parallel and radial line developments in the Tinsmith's Course is applicable to this course also.

INTERSECTIONS AND DEVELOPMENTS.

The following problems on parallel line developments have been selected because they have a particular bearing on pipe work arising in the sheet-metal trade. All of the problems that will follow should be carefully studied, drawn on cheap paper, and proven by cardboard models. These models will at once show any error in the patterns which might otherwise be overlooked. As only the Examination Plates are to be sent to the School, the student should draw all the other plates given in this course.

The first problem to be drawn is shown in Fig. 2, being the intersection between a cylinder and octagonal prism. In drawing these problems for practice, make the cylinder and octagonal prism both 2 inches in diameter. The height of the cylinder from B to E should be 4½ inches; and the length of the prism from G to H, 3 inches. Let A represent the plan of the cylinder, shown in elevation by B C D E; and F, the section of the prism, shown in plan by G H I J. Number the corners of the section F as shown, from 1 to 4 on both sides; and from these points draw horizontal lines intersecting the plan of the cylinder at 2′3′ and 1′4′ on both sides as shown. Establish a convenient intermediate point of intersection between the corners of the prism, as *a* and *a* in A, from which draw horizontal lines intersecting the section F at *a′*, *a′*, *a′*, and *a′*. Take a tracing of the section F with its various intersections, and place it in its proper position as shown by F^1, in the

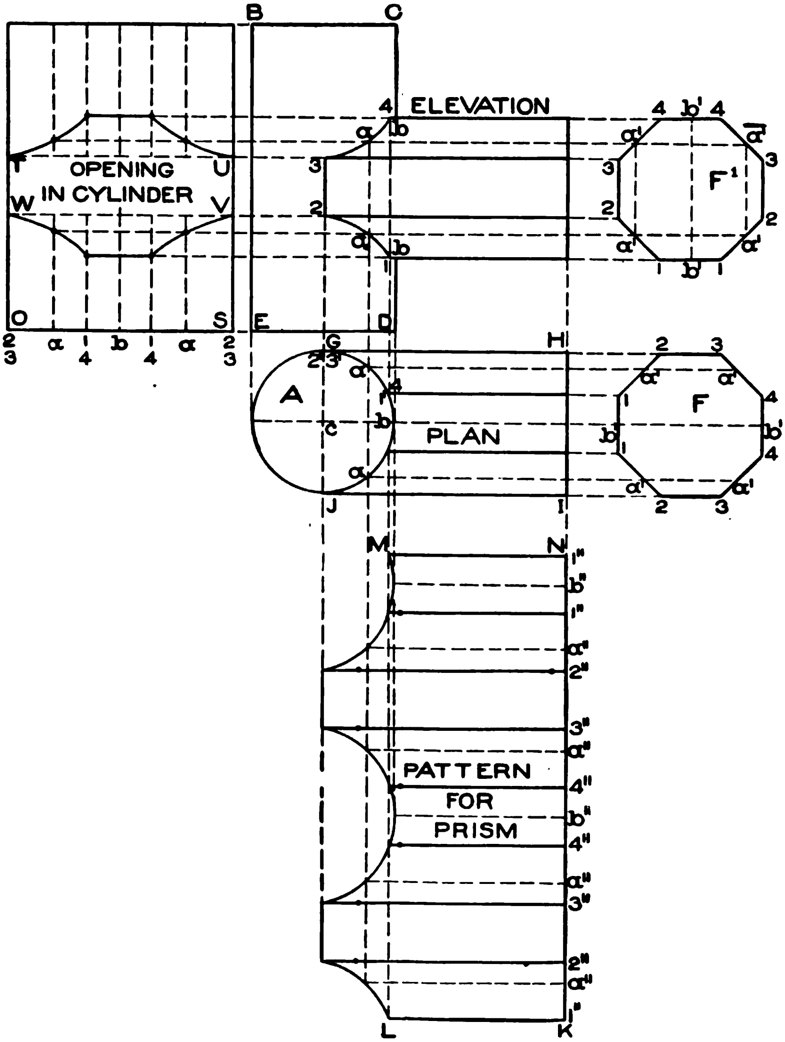


Fig. 2.

center of the cylinder B C D E, allowing the section to make a quarter turn, and bringing the points *b′* *b′* at the top and bottom on a vertical line, while in the section F, *b′* *b′* are on a horizontal line. From the various intersections in F^1, draw horizontal lines intersecting vertical lines drawn from similarly numbered intersections in the plan A, as shown in elevation. A line drawn through these points will represent the joint between the cylinder and prism.

For the development for the prism, extend the line H I in plan as N K, upon which place the stretchout of all the points contained in the section F, as shown by similar figures and letters on N K. Through these points, at right angles to N K, draw lines which intersect with lines drawn from similarly numbered points and letters in plan, at right angles to J I. Trace a line through points thus obtained, and K L M N will be the desired pattern. To obtain the development for the opening in the cylinder, extend the line D E in elevation as S O, upon which place the stretchout of all the points contained in the half-circle A, as shown by similar numbers and letters on S O. At right angles to S O and through these points, draw lines intersecting horizontal lines drawn from intersections having similar numbers and letters in elevation, thus obtaining the intersections shown by T U V W, which will be the shape of the opening to be cut into one-half of the cylinder.

In Fig. 3 is shown the intersection between a hexagonal and quadrangular prism, the hexagonal prism being placed in elevation at an angle of 45° to the base line. When drawing this problem for practice, make the height of the quadrangular prism 4½ inches, and each of its sides 2 inches. Place the hexagonal prism at an angle of 45° to the base line, placing it in the center of the quadrangular prism in elevation as shown; and inscribe the hexagonal section in a circle whose diameter is 2½ inches. Let A represent the plan of the quadrangular prism placed diagonally as shown, above which draw the elevation B C D E. In its proper position and proper angle, draw the outline of the hexagonal prism as shown by 1^v 1″ 4″ 4^v; and on 1″ 4″ draw the half section as shown by F, numbering the corners 1″ 2″ 3″ and 4″. From the corner 1′ in the plan A, draw the center line 1′ 4. Take a tracing of the half section F, and place it as shown by F^1, placing the points 1″ 4″ in F on the center line in F^1 as shown. From the corners 1, 2, 3, and 4, draw lines parallel to the center line, intersecting the two sides of A (*b* 1′ and 1′ *a*) at 2′ 3′ and 1′ 4′, as shown. From these intersections draw vertical lines, which intersect by lines drawn parallel to $4''$ 4^v from corners having similar numbers in F, thus obtaining the points of intersection 1^v 2^v 3^v and 4^v. Dropping vertical lines from the intersections on the plane $1''$ $4''$ in elevation, and intersecting similarly numbered lines in plan, will give the horizontal section of $1''$ $4''$, as shown by 1° 2° 3° and 4°.

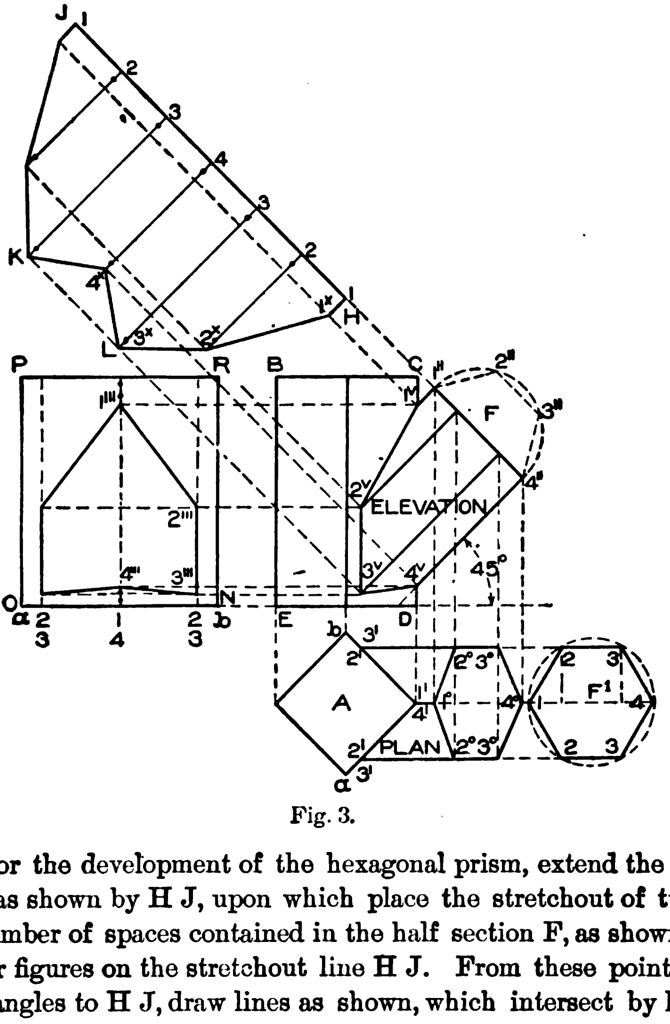


Fig. 3.

For the development of the hexagonal prism, extend the line $4''$ $1''$ as shown by H J, upon which place the stretchout of twice the number of spaces contained in the half section F, as shown by similar figures on the stretchout line H J. From these points, at right angles to H J, draw lines as shown, which intersect by lines drawn at right angles to the line of the prism from intersections 1^v to 4^v, thus obtaining the points of intersection 1^x to 4^x. Lines traced from point to point as shown by J K L H, will be the required development. The shape of the opening to be cut into the quadrangular prism, is obtained by extending the line D E in elevation as N O, upon which place the stretchout of one-half the section A, with the various points of intersection, as shown by similar figures on O N. At right angles to O N erect lines from these points, which intersect by lines drawn from similarly numbered intersections in elevation at right angles to the quadrangular prism, thus obtaining the points of intersection $1'''$ to $4'''$ on both sides. Then N O P R will be the half development.

Fig. 4 shows the intersection between two cylinders of equal diameters at right angles. Make the height of the vertical cylinder 3 inches, that of the horizontal cylinder 1¼ inches, and the diameters of both 2 inches. Let A represent the plan of the vertical cylinder, and B its elevation. Draw the plan of the horizontal cylinder C, shown in elevation by D placed in the center of the vertical cylinder. Draw the half section E in plan and divide it into equal parts, as shown from 1 to 3 to 1. In a similar manner draw the half section E^1 in elevation, which also divide into the same number of spaces as E, reversing the numbers as shown.

The following suggestions are given to avoid confusion in numbering the points or corners of irregular or round sections in plan and elevation. If the half section E were bent on the line 1–1 and turned upward toward the reader, and we should view this section from the front, the point 3 would be at the top, or, if bent downward, would be at the bottom; therefore the points 3 and 3 in elevation are placed at top and bottom. Now if the section E^1 in elevation were bent on the line 3-3 either toward or away from the reader, the point 1 when looking down would show on both sides as shown in plan, which proves both operations. No matter whether the form is simple, as here shown, or complicated as that which will follow, the student should use his imaginative power. Study the problem well; close your eyes and imagine you see the finished article before you, or, failing in this, make a rough model in the shop or a cardboard model at home, which will be of service. Now from the intersections in E, draw horizontal lines intersecting the circle A at $1'$, $2'$ and $3'$ on both sides. From these points erect perpendicular lines and intersect them with horizontal lines drawn

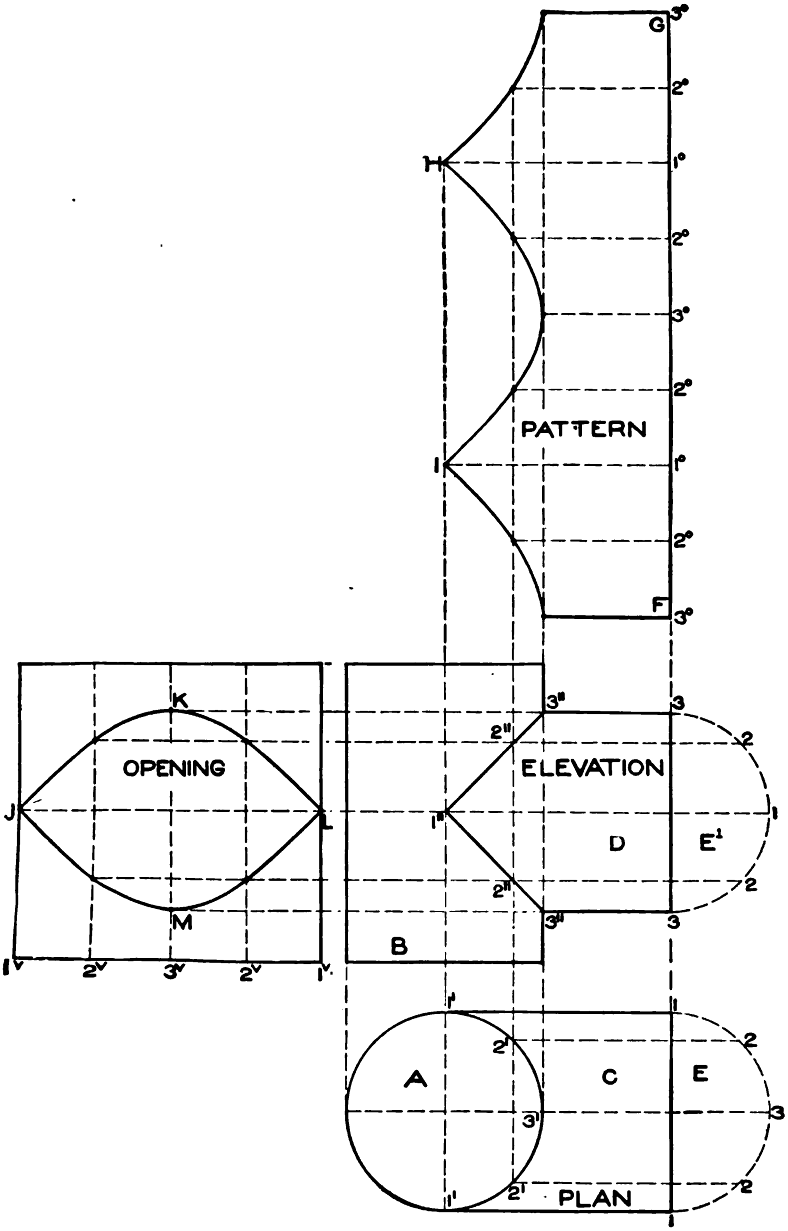

G
3°
2°
H
1°
2°
3°
2°
PATTERN
I
1°
2°
F
3°
K
OPENING
J
L
M
1v
2v
3v
2v
1v
B
3''
2''
ELEVATION
1''
D
E¹
2''
3''
3
2
1
2
3
1'
2'
A
C
E
3'
2'
1'
PLAN
1
2
3
2

Fig. 4.

from similarly numbered intersections in E^1. Lines traced through these points $3'' 2'' 1''$ and $1'' 2'' 3''$ will be straight because both branches are of equal diameters.

For the development of the cylinder D in elevation, extend the line 3-3 as shown by F G, upon which place the stretchout of twice the number of spaces contained in E^1, as shown by similar numbers 3° to 1° to 3° to 1° to 3° on the stretchout line F G. From these points, at right angles to G F, draw lines, and intersect them by lines drawn parallel to the cylinder B from similar numbers in the joint line. Trace a line through these points in the development, when F G H I will be the desired shape.

For the opening to be cut into the cylinder B to receive the cylinder D, extend the base of the cylinder B as shown by $1^v 1^v$, upon which place the stretchout of the half circle A in plan, as shown by similar figures on the stretchout line $1^v 1^v$. From these points erect perpendiculars, which intersect by lines drawn from similarly numbered intersections in elevation at right angles to the line of the cylinder B. Trace a line through the intersections thus obtained; J K L M will be the shape of the opening.

Fig. 5 shows the intersection of two cylinders of unequal diameters at an angle of 45°. Make the diameters of the large and small cylinders 2 inches and 1¼ inches respectively; the height of the large cylinder 3 inches; and the length of the small cylinder measured from its shortest side in elevation, 1 inch, placed at an angle of 45° in the center of the cylinder B. A represents the plan of the large cylinder struck from the center *a* and shown in elevation by B. Draw the outline of the small cylinder C at its proper angle, and place the half section D in its position as shown; divide it into a number of equal spaces, as shown from points 1 to 5. Through the center *a* in plan. draw the horizontal line *a* 5; and with *b* as a center describe a duplicate of the half section D with the various points of intersection, as shown by D^1, placing the points 1 and 5 on the horizontal line *a* 5. From the intersections in D^1 draw horizontal lines intersecting the large circle A at $3'$ to $3'$ as shown, from which points erect perpendicular lines; intersect them by lines drawn parallel to the lines of the smaller pipe from similarly numbered intersections in D. A line traced through the points thus obtained will represent the intersection or miter joint between the two pipes.

These same principles are applicable no matter what diameters the pipes have, or at what angle they are joined, or whether the

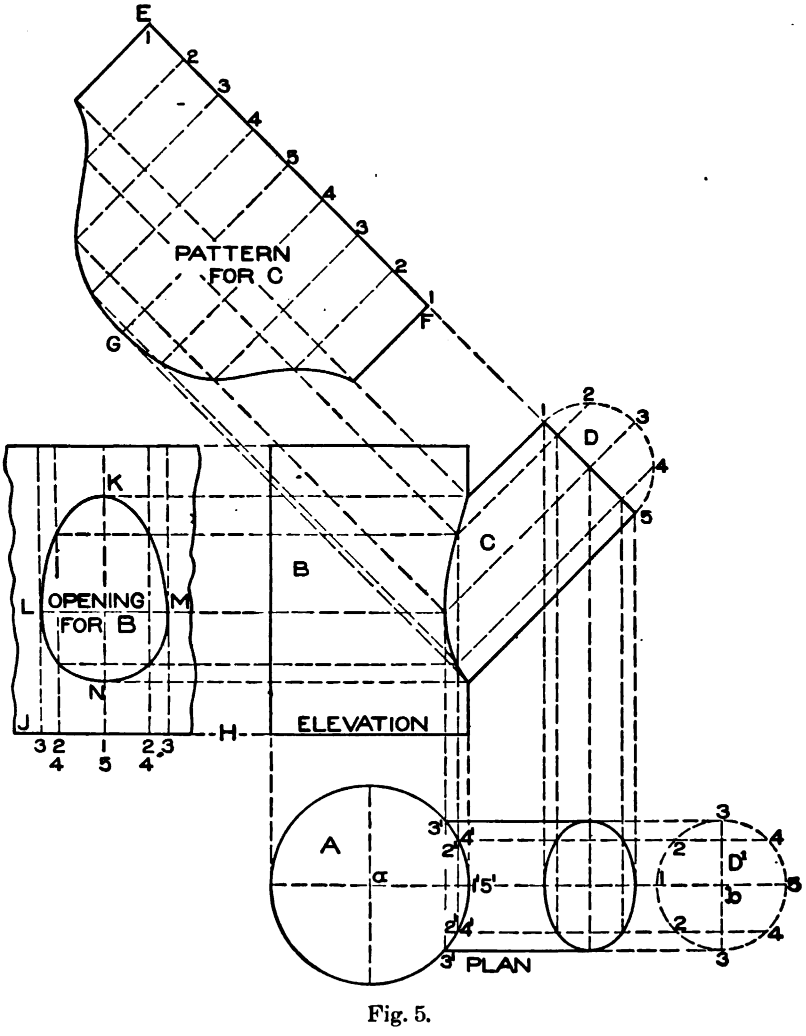


Fig. 5.

pipe is placed as shown in plan or at one side of the center line.

For the development of the small cylinder extend the line 5 – 1 in elevation as shown by F E, upon which place the stretchout of the circle D^1 in plan, or twice the amount of D in elevation, as shown by similar figures on the stretchout line F E. At right angles to F E and through these small figures, draw lines which intersect with lines drawn at right angles to the lines of the small cylinder from similarly numbered intersections in the miter line in elevation. Trace a line through the points thus obtained; E F G will be the development for the cylinder C.

To obtain the opening in the large cylinder extend the lines of the large cylinder in elevation as shown at the base by H J, upon which place the stretchout of the intersections contained in the circle A, being careful to transfer each space separately (as they are unequal) to the stretchout line H J. Through these points and at right angles to H J erect lines which intersect with horizontal lines drawn from similar points in the miter line in elevation A line traced through the points thus obtained, as shown by K L M N, will be the desired development.

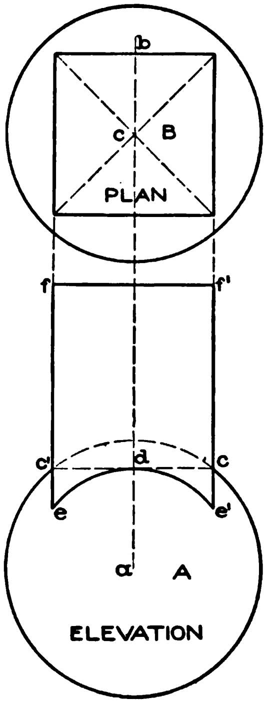


Fig. 6.

Fig. 6 shows the intersection between a quadrangular prism and sphere, the center of the prism to come directly over the center of the sphere. Make the diameter of the sphere 2½ inches, the sides of the prism 1½ inches, and the height from *f* to *c'* 2⅜ inches. Draw the elevation of the sphere A which is struck from the center *a*, from which erect the perpendicular *a b*. With any point, as *c*, as a center and using the same radius as that used for A, describe the plan B. Through *c* draw the two diagonals at an angle of 45°, and draw the plan of the prism according to the measurements given. Now draw the elevation of the prism *f c'* and *f' c*, the sides of the prism intersecting the sphere at *c* and *c'*. From either of these points draw a horizontal line intersecting the center line *a b* at *d*. Then using *a* as a center and *a d* as the radius, describe the arc *e e'* intersecting the sides of the prism extended at *e* and *e'*; *f e e' f'* will be the development for one of the sides of the prism. In practice the four sides are joined in one.

Fig. 7 shows the intersection of a quadrangular prism and sphere when the center of the prism is placed to one side of the center of the sphere. Make the diameter of the sphere the same as in the preceding figure; through *x* in the plan draw the 45° diagonal, and make the distance from *x* to A ½ inch, the sides of the prism 1 inch, and the height from E to *c* in elevation 1½ inches. Having drawn the elevation and plan of the sphere, construct the plan of the prism as shown by A B C D. Parallel to the center line *x y* project the prism in elevation intersecting the sphere at *a* and *c*. Now since the center of the sphere is on one of the diagonals of the prism in plan, either two of the sides meeting at one end of that diagonal, as B C and C D, will be alike, and both will be different from the other two sides A B and A D, meeting at the opposite end of the diagonal. Therefore the line F *a* in elevation will be used in obtaining the development of D C in plan, while the line E *c* will be used in obtaining the development for the two sides D A and A B in plan.

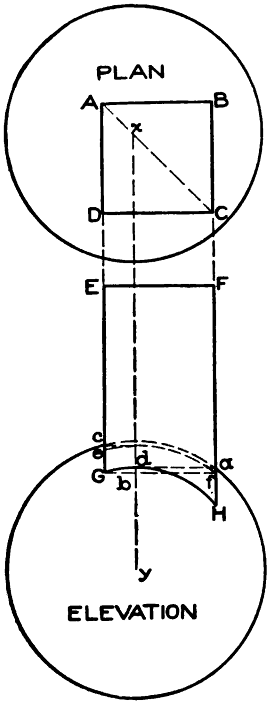


Fig. 7.

Now from *a* draw a horizontal line intersecting the center line *x y* at *b;* and using *y* as a center and *y b* as the radius, describe the arc G H intersecting the sides of the prism extended to G and H. Then E F G H is the development for each side of the prism shown in plan by D C and C B. In a similar manner, from the intersection *c* in elevation draw a horizontal line intersecting the center line *x y* at *d*. Then using *y* as center and *y d* as radius, describe an arc intersecting the sides of the prism at *e* and *f*. E F *f e* will show the development for either side of the prism shown in plan by D A and A B. By connecting the points G and *f* it will be found that the line is a true horizontal line, which proves the two developments. Should the plan of the prism be so placed on the sphere that all sides would be different, then two elevations would be necessary so that the intersections of all the sides could be shown.

Developments by Triangulation. In developing sheet-metal work of irregular forms, patterns are required which cannot be developed by either the parallel or radial-line methods. These irregular shapes are so formed that although straight lines can be drawn upon them the lines would not run parallel to one another, nor would they all incline to a common center. In the methods previously described, the lines in parallel developments run parallel to one another, while in radial-line developments all the lines meet at a common center. Hence in the development of any irregular article, it becomes necessary to drop all previous methods, and simply proceed to measure up the surface of the irregular form, part by part, and then add one to another until the entire surface is developed. To accomplish this, one of the simplest of all geometrical problems is made use of and shown in Part II of Mechanical Drawing, Plate V, Problem 11, entitled "To construct a triangle having given the three sides." To carry out this method it is necessary only to divide the surface of the plan or elevation of any irregular article into a number of equal parts. Use the distances in plan as the bases of the triangles, and the distances in elevation as the altitudes or heights of the triangles, or *vice versa;* and then find the hypothenuse by connecting the two given lengths.

To illustrate this simple principle Fig. 8 has been prepared. Let A B C D represent the plan of a plane surface, shown in elevation by A^1 B^1. We know that the true length of the plane is equal to A^1 B^1 and the true width is equal to A D or B C in plan. We also know that the vertical height from the bottom of the plane A^1 to the top B^1 is equal to B^1 *b* as shown. But suppose we want to obtain the true length of the diagonal line B D in plan on the developed plane. To obtain this it will be necessary only to take the length of B D, place it from *b* to D^1, and draw a line as shown from B^1 to D^1, which is the length desired.

While this may look very simple, it is all that there is to triangulation, and if the student thoroughly understands the simple principle and studies the problems which will follow, he will have no trouble in applying this principle in complicated work. To make it still clearer we will prove the length of the line B^1 D^1. Take the distance of A^1 B^1, place it in plan as shown by A B^2, and complete the rectangle A B^2 C^2 D. Draw the diagonal B^2 D, being the length sought, which will be found to equal B^1 D^1 in elevation. When drawing this problem in practice, make the plan 4 by 6 inches and the vertical height in elevation 5 inches.

In obtaining developments by triangulation. the student should use all of his conceptive powers as previously explained. Before making any drawing, he must see the article before him in his mind's eye, so to speak, before he can put it down on paper. Therefore we want to impress upon the student the necessity of drawing all the problems that will follow in this part and in the Practical Workshop Problems. It should be understood that triangulation is not given as an alternative method, but is used when no other method can be employed, and without it no true pattern could be obtained for these irregular shapes; hence the necessity of close study.

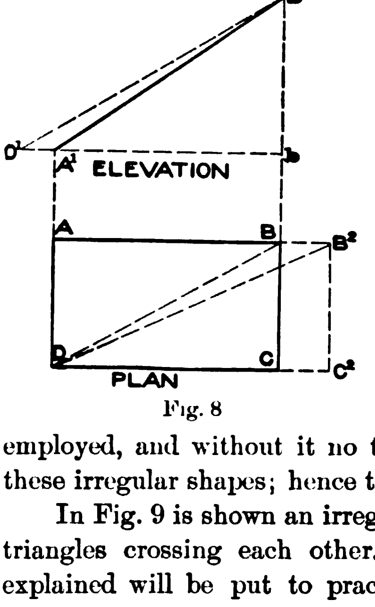


Fig. 8

In Fig. 9 is shown an irregular solid whose base and top are triangles crossing each other. and in which the principle just explained will be put to practical test Inscribe the triangles shown in plan in a circle whose radius is equal to *a* 1, or 1½ inches, and make the height of the article in elevation 2 inches. The dotted triangles 1 2 3 in plan represent the section of the article on the line 2–3 in elevation: and the solid triangle 1^1 2^1 3^1 in plan, the section on the line 2^1 3^1 in elevation. Now connect the two sections in plan by drawing lines from 1 to 2^1 and to 3^1, from 2 to 2^1 and to 1^1, and from 3 to 1^1 and to 3^1. In a similar manner connect the points in elevation as shown. It now becomes necessary to obtain a triangle giving the true length of the lines connecting the corners of the triangle in plan, and as all of these lines are equal only one triangle is necessary Therefore take the distance from

1 to 2^1 in plan and place it on the line 3–2 extended in elevation, as shown from 2 to 1°, and draw a line from 1° to 2^1, which is the desired length.

For the pattern, proceed as is shown in Fig. 10. Take the distance of any one of the sides in the triangle, as 1–2 in Fig. 9, and place it on the horizontal line 1–2 in Fig. 10. Then using 1 and 2 as centers, with 1° 2^1 in elevation in Fig. 9 as radius, describe the arcs in Fig. 10 intersecting each other in 2^1. Then 1 2 2^1 will be the pattern for one of the sides shown in plan in Fig. 9 by 1 2 2^1. Proceed in this manner in Fig. 10 as shown by the small arcs; or a tracing may be taken of the one side 1 2 2^1, and traced as shown until six sides are obtained, which will be the full pattern and which is numbered to correspond to the numbers in plan.

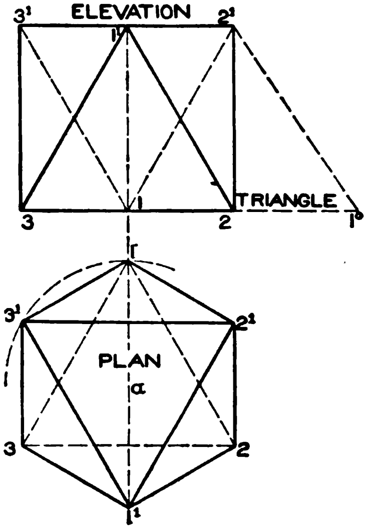


Fig. 9.

In Figs. 11, 12, and 13 are shown the methods used in developing a scalene cone. The method of obtaining the development of any scalene cone, even though its base is a perfect circle, is governed by the same principle as employed in the last problem on triangulation

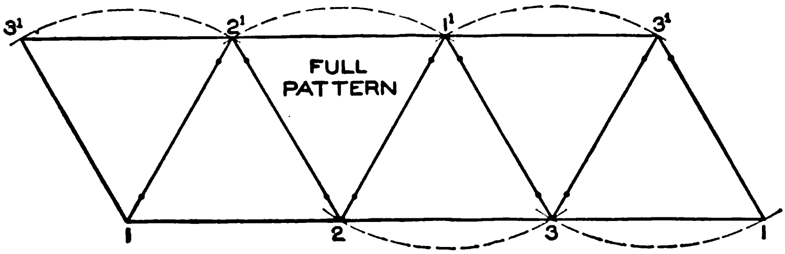


Fig. 10.

It is well to remember that any section of a scalene cone drawn parallel to its base will have the same shape (differing of course in size) as the base. This is equally true of articles whose bases are in the shape of a square, rectangle, hexagon, octagon, or any other polygon. What has just been explained will be proven in connection with Fig. 11, in which A B C represents a side elevation of a scalene cone, whose plan is shown by 1 4^1 7 4 C^1. Draw any horizontal line, as A D, on which set off the distances A B equal to 3 inches and B D equal to 2½ inches, and the vertical height D C equal to 4½ inches. Draw lines from B and A to C, which completes the elevation. In its proper position below the line A B, draw the plan of A B as 1 4 7 4^1 struck from the center C. Through C draw the horizontal line C C^1, and

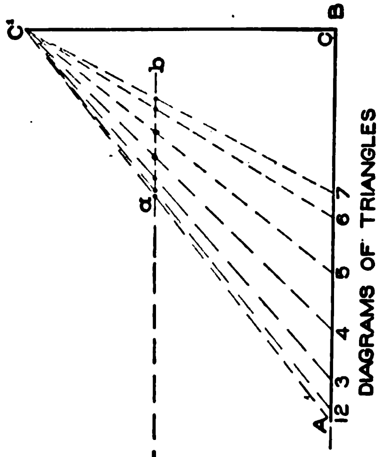


Fig. 12.

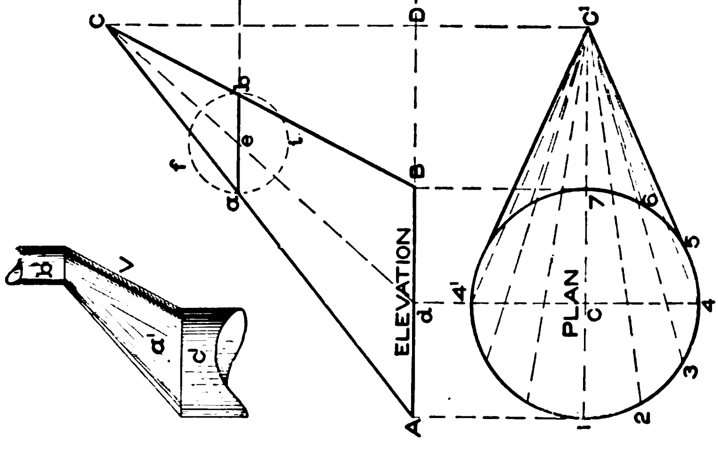


Fig. 11.

intersect it by a vertical line drawn from the apex C in elevation, thus obtaining the apex C^1 in plan. Draw lines from 4 and 4^1 to C^1, which completes the plan.

As both halves of the scalene cone are symmetrical, it is necessary only to divide the half plan 1 4 7 into a number of equal spaces as shown by the small figures 1 to 7, and from points thus obtained draw radial lines to the apex C^1. Then these lines in plan will represent the bases of triangles which will be constructed, whose altitudes are all equal to D C in elevation. Therefore in Fig. 12 draw any horizontal line, as A B, and from any point, as C, erect the perpendicular line C C^1 equal in height to D C in Fig. 11. Now from C^1 in plan take the various lengths of the lines 1 to 7 and place them on the line A B in Fig. 12, measuring in every instance from the point C, thus obtaining the intersections 1 to 7, from which lines are drawn to the apex C^1. Then these lines will represent the true lengths of similarly numbered lines in plan in Fig. 11.

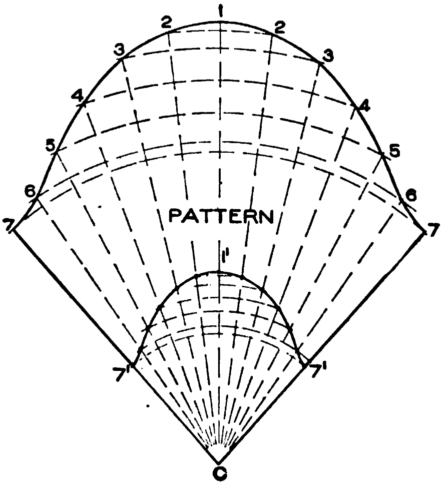


Fig. 13.

For the pattern proceed as is shown in Fig. 13. With C as center and radii equal to C^1 7, 6, 5, 4, etc., in Fig. 12, describe the arcs 7–7, 6–6, 5–5, 4–4, etc., in Fig. 13 as shown. Now assuming that the seam is to come on the short side of the cone, as C B in Fig. 11, set the dividers equal to one of the equal spaces in the plan; and starting on the arc 7–7 in Fig. 13, step from arc 7 to arc 6, to arcs 5, 4, 3, 2, and 1, and then continue to arcs 2, 3, etc., up to 7. Trace a line through these intersections as shown by 7-1-7, and draw lines from 7 and 7 to C, which completes the pattern.

Now to prove that any section of an oblique or scalene cone cut parallel to its base, has a similar shape to its base (differing in size), draw any line as *a b* in Fig. 11 parallel to A B. From C in plan erect a vertical line intersecting the base line A B at *d*, from which draw a line to the apex C, cutting the line *a b* at *e*. Then the distances *e a* and *e b* will be equal; and using *e* as a center and *e b* as radius, describe the circle *a f b i*, which is the true section on *a b*. Then *a b* B A will be the frustum of a scalene cone. Extend the line *a b* parallel to A D, cutting the diagram of triangles in Fig. 12 from *a* to *b*. Then with radii equal to the distances from C^1 to the various intersections on the line *a b*, and using C in Fig. 13 as center, intersect similarly numbered radial lines drawn from 7 to 1 to 7 to the apex C. A line traced as shown from 7′ to 1′ to 7′ will be the desired cut, and 7-7-7′-7′ will be the pattern for the frustum. The practical use of this method is shown in diagram V in Fig. 11; *a′* is the frustum of the oblique cone, on the ends of which are connected round pipes *b′* and *c′*.

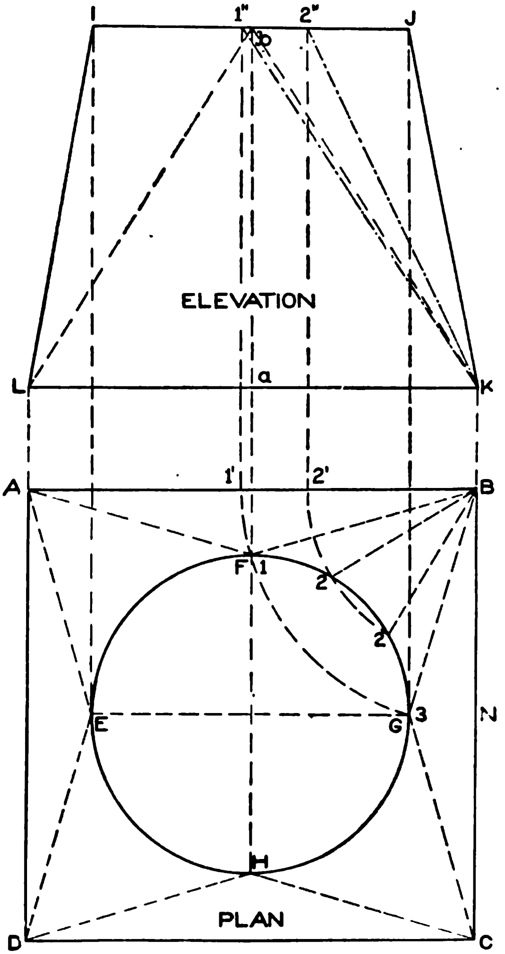


Fig. 14.

It is shown in Fig. 14 how in an irregular solid whose base is square and top is round, both top and bottom on horizontal planes are developed. The corners in plan F B G, G C H, H D E and E A F should be considered as sections of scalene cones. Proceed by drawing the plan A B C D 3½ inches square, which represents the plan of the base of the article; and the circle E F G H 2½ inches in diameter, which shows the plan of the top of the article; the vertical height to be 3 inches, shown from *a* to *b*. As the circle is in the center of the square, making the four corners symmetrical, it is necessary only to divide the one-quarter circle into a number of equal parts as shown by the small figures 1, 2, 2, 3, from which draw lines to the apex B. Complete the elevation as shown by I J K L. Now using B as center, and radii equal to B 1 and B 2 in plan, describe arcs intersecting A B at 1′ and 2′ as shown. From these points erect perpendiculars intersecting the top of the article I J in elevation at 1″ and 2″, from which draw lines to K. Then K 1″ and K 2″ will be the true lengths of the lines shown in plan by B 1 and B 2 respectively on the finished article.

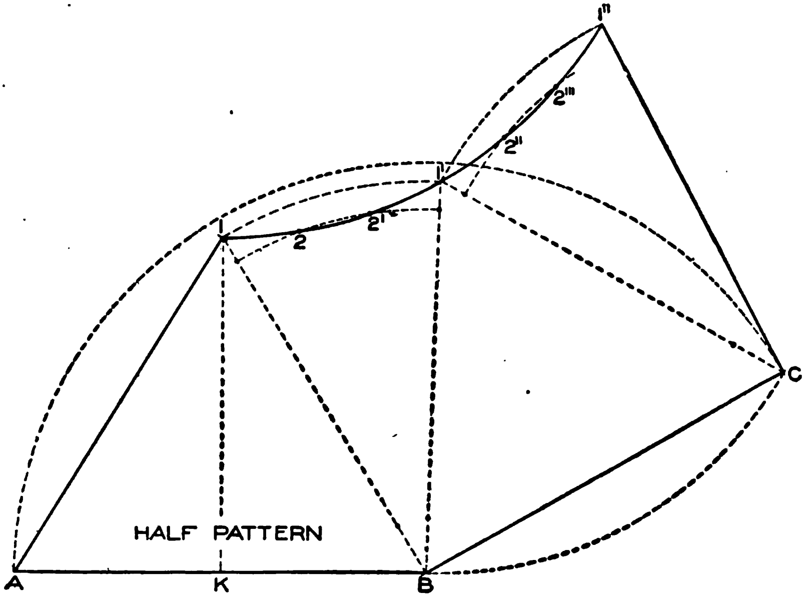


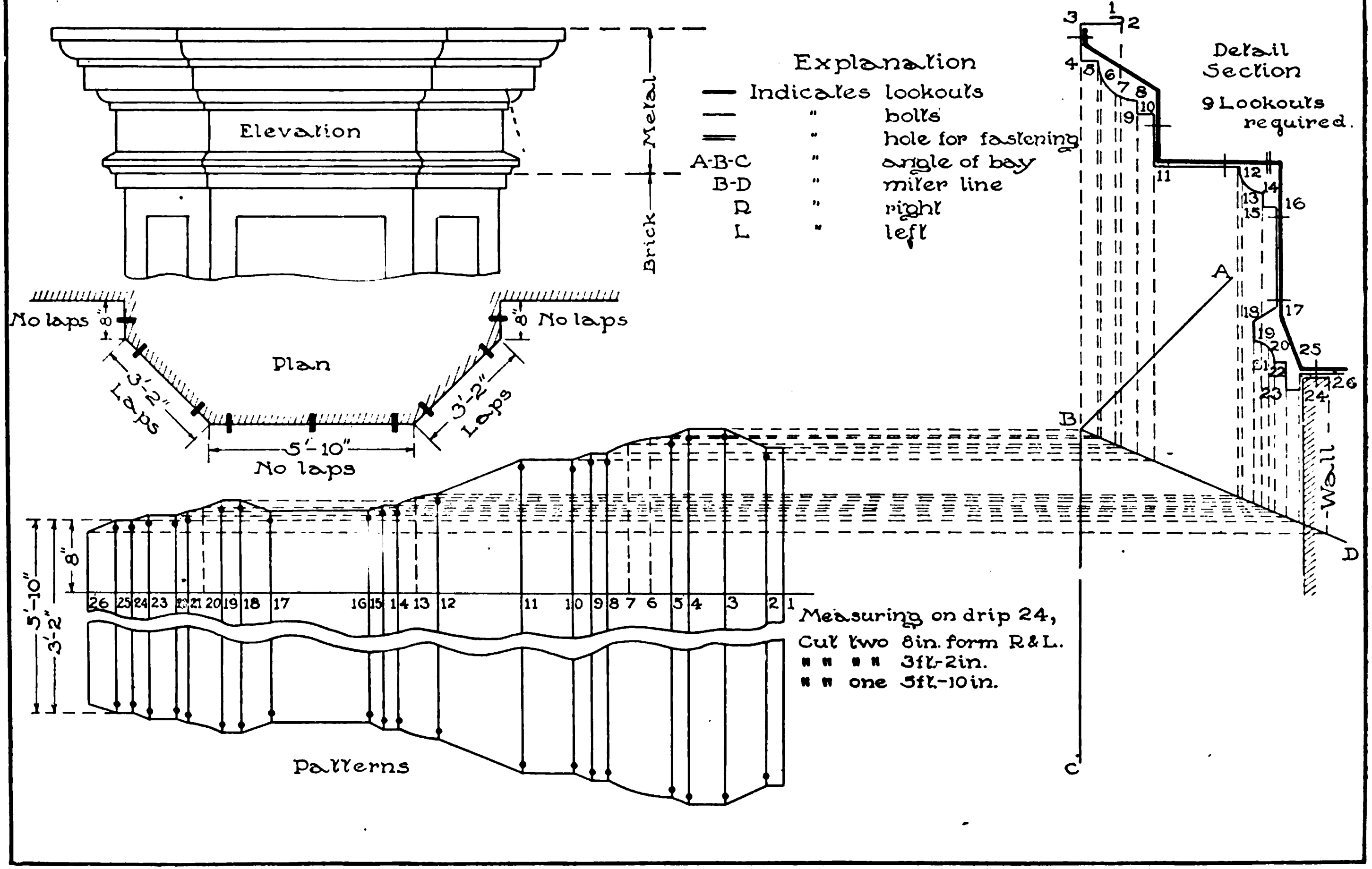
Fig. 15.

For the half pattern proceed as follows: In Fig. 15 draw any horizontal line, as A B, equal in length to A B in plan in Fig. 14. Now with K 1″ as radius and A and B in Fig. 15 as centers, describe arcs intersecting each other at 1 From 1 drop a vertical line intersecting A B at K. Then 1 K should equal J K in elevation in Fig. 14, which represents the true length through G N in plan.

Now with radii equal to K 1′ and K 2′ in elevation, and with B in Fig. 15 as center, describe the arcs 1–1′ and 2–2′. Now set the dividers equal to one of the spaces in G F in plan in Fig. 14; and starting at 1 in Fig. 15, step off arcs having similar numbers as shown by 1, 2, 2′, 1′. Now using 1 B as radius, and 1′ as center, describe the arc B C, and intersect it by an arc struck from B as center and with B A as radius, as shown at C. Take a tracing of 1 B 1′ and place it as shown by 1′ C 1′. Now connect the various intersections by drawing lines from 1 to A to B to C to 1′ to 1′ to 1, which completes the half pattern. The triangular pieces 1 A B or 1′ B C will represent the flat sides of the article shown in plan by 1 A B or 3 B C respectively in Fig. 14; and the cone patterns 1–1′ B and 1′–1′ C in Fig. 15, the sections of the scalene cones 1–3–B and H–G–C respectively in plan in Fig. 14. This same rule is applicable whether the top opening of the article is placed exactly in the center of the base or at one side or corner. Various problems of this nature will arise in Practical Workshop Problems; and if the principles of this last problem are thoroughly understood, these will be easily mastered.

Approximate Developments. In developing the blanks or patterns for sheet-metal work which requires that the metal be hammered or raised by hand, or passed between male and female dies in foot or power presses, circular rolls, or hammering machines, the blanks or patterns are developed by the approximate method, because no accurate pattern can be obtained. In all raised or pressed work in sheet metal, more depends upon the skill that the workman has with the hammer, than on the patterns, which are but approximate at their best. While this is true, it is equally true that if the workman understands the scientific rule for obtaining these approximate patterns a vast amount of time and labor can be saved in bringing the metal to its proper profile. If the true rule for averaging the various shapes and profiles in circular work is not understood, the result is that the blank has either too little or too great a flare and will not form to its proper profile and curve. Before proceeding to describe the approximate development methods, attention is called to the governing principle underlying all such operations. We have previously shown how the patterns are developed for simple flaring ware; in other words, how to

PATTERNS AND LAY-OUT FOR CORNICE OVER BRICK BAY



develop the frustum of a cone. The patterns for curved or any other form of circular or hammered work are produced upon the same principle. The first illustration of that principle is shown in Fig. 16, in which A B C D represents a sphere 3 inches in diameter composed of six horizontal sections, struck from the center *a*.

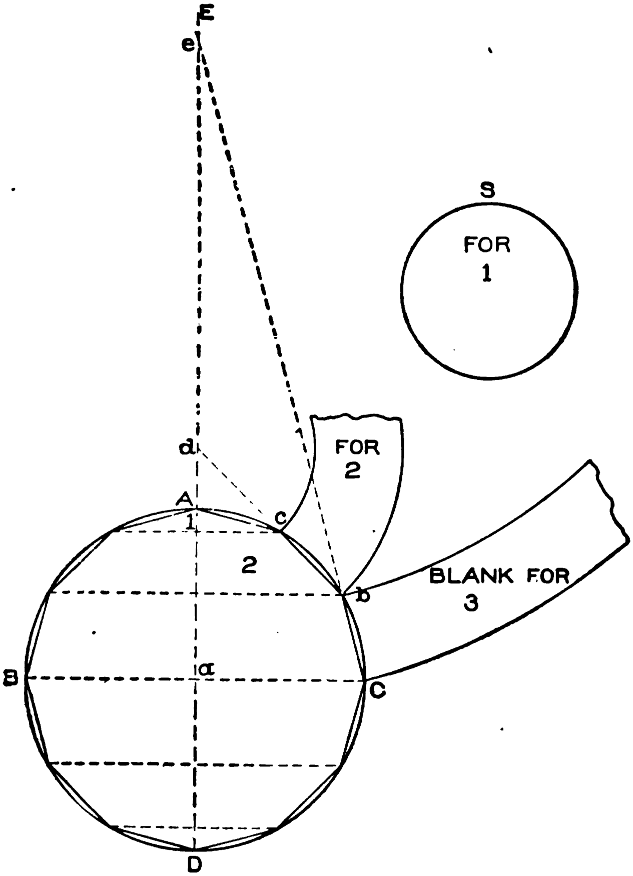


Fig. 16.

Divide the quarter circle A C into as many parts as there are sections required in the half sphere (in this case three), and draw horizontal lines through the ball as shown. The various radii for the patterns are then obtained by drawing lines through C *b*, *b c*, and *c* A. Thus C *b* extended meets the center line E D at *e*, which is the center for striking the blank for number 3, using the radii *e b* and *e* C. In similar manner draw a line from *b* to *c*, extending it until it meets E D at *d*. Then *d c* and *d b* will be the radii for blank number 2, while A *c* is the radius for blank 1 shown at S. The lengths of the pattern pieces are determined in the same manner as would be the case with an ordinary flaring pan in producing the patterns for tin ware, and will be explained thoroughly in the Practical Workshop Problems which will shortly follow.

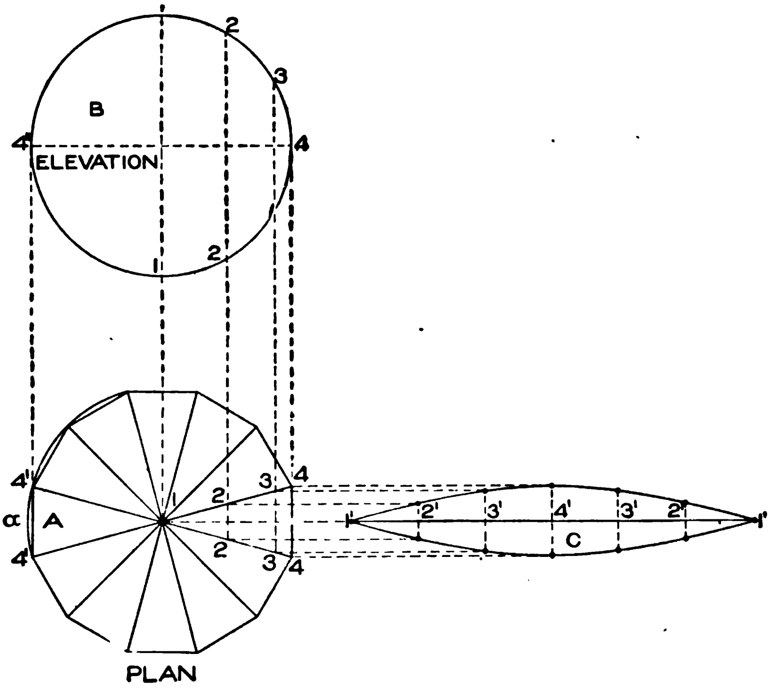


Fig. 17.

In Fig. 17 is shown another elevation of a sphere composed of twelve vertical sections as shown in plan view. While the method used for obtaining the pattern is by means of parallel lines, and would be strictly accurate if the sections in plan remained straight as from 4 to 4, the pattern becomes approximate as soon as we start to raise it by means of machine or hammer to conform to the profile B in elevation, because the distance along the curve *a* from 4′ to 4′

in plan is greater than a straight distance from 4 to 4. The pattern by this method is obtained as follows: Let B represent the elevation of the sphere, and A the plan of the same, which is divided into as many sides as the sphere is to have vertical sections, in this case 12, being careful that the two opposite sides 4–4 and 4′ 4′ in plan run parallel to the center line as shown. Make the diameter of the sphere 4–4″ 3 inches. Divide the half elevation into an equal number of spaces as shown from 1 to 4 to 1, and from these points drop lines at right angles to 4–4″ intersecting the miter lines 1–4 in plan as shown. Now draw any horizontal line, as 1′–1′, upon which place the stretchout of 1–4–1 in elevation as shown by 1′–4′–1′ on the line 1′–1′ in C. Through these points draw lines at right angles to 1′–1′, which intersect by lines drawn from similarly numbered intersections on the miter lines 1–4 in plan, at right angles to 4–4. A line traced through points thus obtained as shown by C will be the desired pattern.

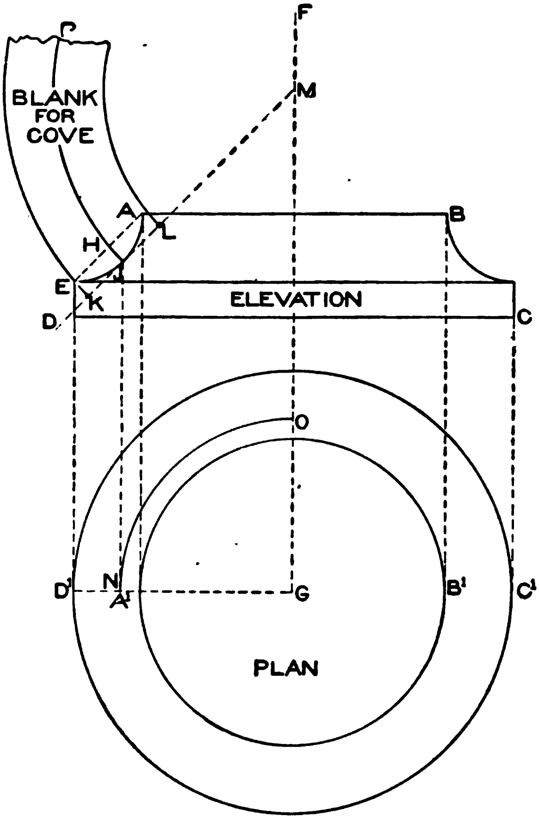


Fig. 18.

In Fig. 18 is shown the principle used in obtaining the radii with which to develop the blank for a curved or circular mould when it is to be hammered by hand. In this connection, only the principle employed will be shown, leaving the full development and also the development for patterns which are to be raised by hand

and hammered by machine, to be explained in problems which will follow in Practical Workshop Problems. Draw this problem double the size shown. First draw the elevation A B C D, and through the elevation draw the center line F G. Then using G as a center, draw the circles A^1 B^1 and C^1 D^1 representing respectively the horizontal projections of A B and C D in elevation. Now draw a line from A to E in elevation, connecting the corners of the cove as shown. Bisect A E and obtain the point H, from which at right angles to A E draw a line intersecting the cove at J. Through J parallel to A E draw a line intersecting the center line F G at M. Take the stretchout from J to A and from J to E and place it on the line J M as shown respectively from J to L and from J to K. Then will M L and M K be the radii with which to strike the pattern or blank for the cove. From J drop a vertical line intersecting the line D^1 G in plan at N. Then with G as center strike the quarter circle N O. Now using M as center and M J as radius, strike the arc J P. Then on this arc, starting from J, lay off 4 times the stretchout of N O in plan for the full pattern. It should be understood that when stretching the cove A E, the point J remains stationary and the metal from J to L and from J to K is hammered respectively toward J A and J E. For this reason is the stretchout obtained from the point J.

PRACTICAL WORKSHOP PROBLEMS.

In presenting the 32 problems which follow on sheet-metal work, practical problems have been selected such as would arise in every-day shop practice.

In this connection we wish to impress upon the student the necessity of working out each and every one of the 32 problems. Models should be made from stiff cardboard, or, if agreeable to the proprietor of the shop, the patterns can be developed at home, then cut out of scrap metal in the shop during lunch hour, and proven in this way.

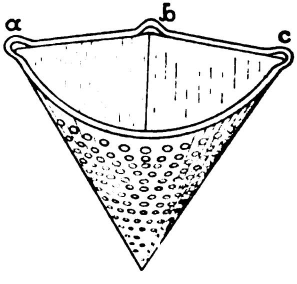


Fig. 19.

Our first problem is shown in Fig. 19, and is known as a sink drainer. It is often the case that the trap under the kitchen sink is choked or blocked, owing to a collection of refuse matter. To avoid this a sink drainer is used, and is fastened in position through the wire loops *a*, *b* and *c*. The refuse matter is poured into the drainer, from which it is easily removed after the fluid has passed through the perforations. These drainers may be made of tin or of black or galvanized iron, but where a good job is wanted 16-ounce copper should be used. To obtain the pattern for any sized drainer, proceed as follows: First draw the plan of the drainer A B C in Fig. 20, making A B and B C each two inches and forming a right angle. Then using B as center and A B as radius, draw the arc A C. In its proper position above the plan construct the side elevation, making E D 2 inches high, and draw the line F D. Then will F E D be the side elevation. Divide the arc A C into equal spaces as shown by the small figures 1 to 5. For the pattern use F D as radius, and with D in Fig. 21 as center strike the arc 1 5. From 1 draw a line to D and step off on 1–5 the same number of spaces as contained in A C in plan in Fig. 20, as shown by similar figures in Fig. 21. Draw a line from 5 to D. Then will 1–5–D be the pattern for the front of the strainer, in which perforations should be punched as shown. To join the sides of this pattern, use 1 and 5 as centers, and with either F E or A B in Fig. 20 as radius, describe the arcs E and E¹ in Fig. 21. Now using D as center and D E in Fig. 20 as radius, intersect the arcs E and E¹ as shown in Fig. 21. Draw lines from 1 to E¹ to D to E to 5, which completes the pattern, to which edges must be allowed for wiring at the top and seaming at the back.

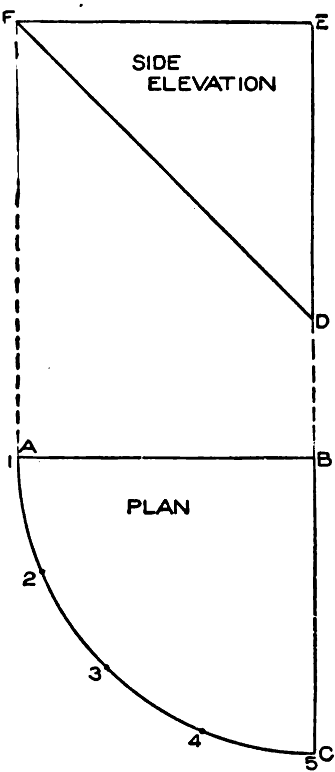


Fig. 20.

When joining a faucet or stop cock to a sheet-metal tank it is usual to strengthen the joint by means of a conical "boss," which is indicated by A in Fig. 22. In this problem the cone method is employed, using principles similar to those used in developing a frustum of a cone intersected by any line. Therefore in Fig. 23 let

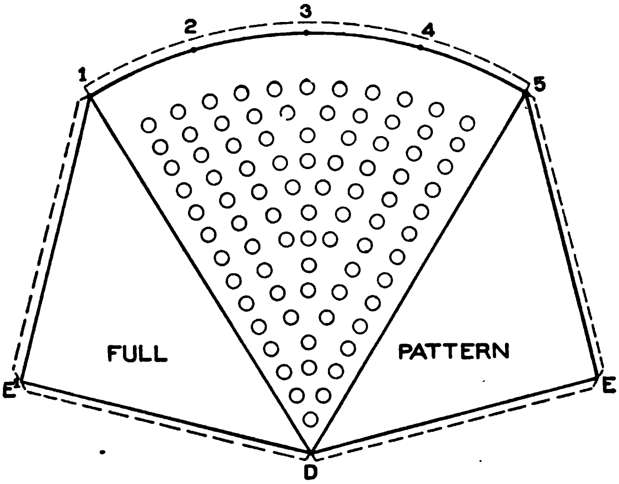


Fig. 21.

A B represent the part plan of the tank, C portion of the faucet extending back to the tank line, and F G H I the conical "boss" to fit around a faucet. When drawing this problem make the radius of the tank D A equal to 3½ inches, and from D draw the vertical line D E. Make the distance from G to H equal to 2¾ inches, the diameter of the faucet F I 1¼ inches and the vertical height K C 1½ inches Draw a line from G to H intersecting the center line D E at K. Then using K as center describe the half section G J H as shown. Divide J H into equal parts shown from 1 to 4, from which drop vertical lines intersecting the line G H as shown, from which draw radial lines to the apex E cutting the plan line

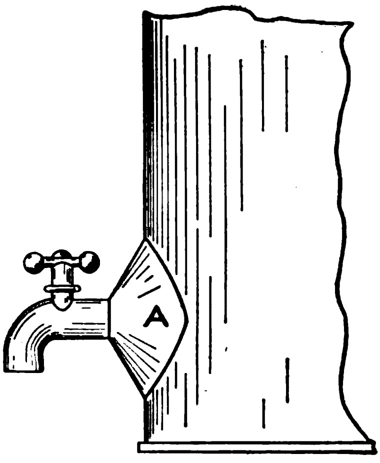


Fig. 22.

of the tank A B as shown. From these intersections draw horizontal lines intersecting the side of the cone H I at 1, $2'$, $3'$, and $4'$. Now use E as center, and with radius equal to E 1 describe the

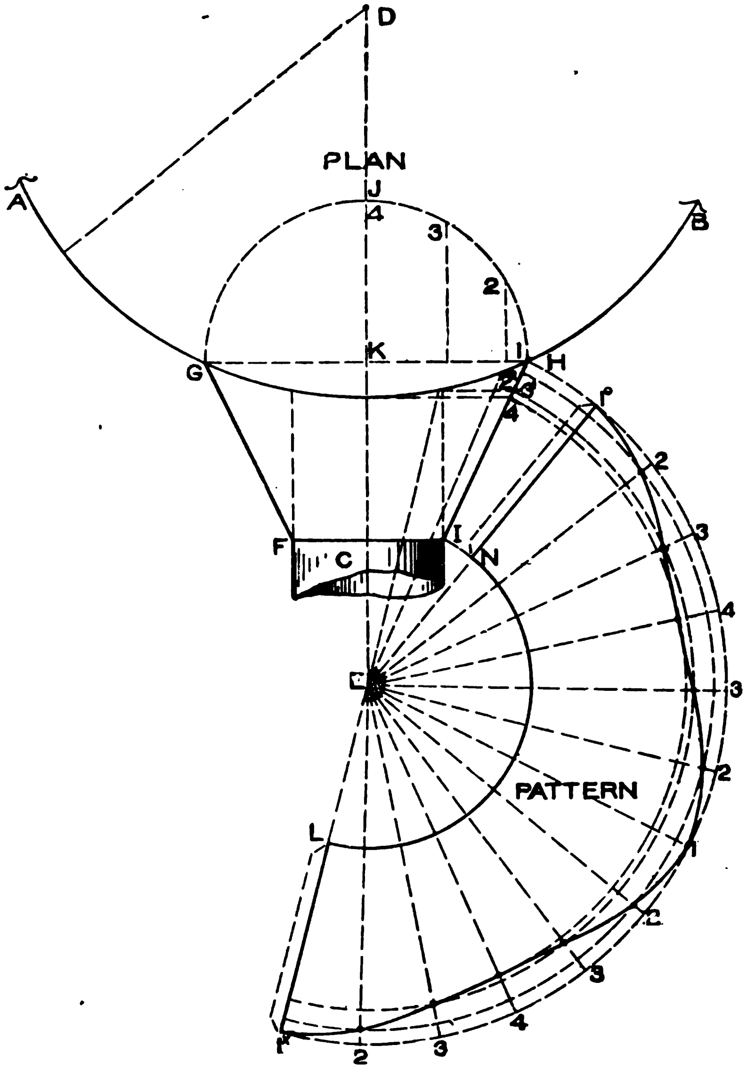


Fig. 23.

arc 1°-1^x as shown. Draw a line from 1° to E, and starting from 1° set off on 1°-1^x four times the number of spaces contained in

J H in plan, as shown by similar numbers on 1° 1^{x}. Draw a line from 1^{x} to E, and with E I as radius describe the arc N L intersecting the radial lines 1° E and 1^{x} E at N and L respectively. From the various numbers on the arc 1° 1^{x} draw radial lines to the apex E; and using E as center and with radii equal to E 4′, E 3′, and E 2′, draw arcs intersecting similarly numbered radial lines as shown. Trace a line through points thus obtained; then will N 1° 1 1^{x} L be the pattern for the "boss."

In Fig. 24 is shown what is known as a hip bath. In drawing out the problem for practice the student should remember that it is similar to the preceding one, the only difference being in the outline of the cone. Make the top of the cone I B in Fig. 25 equal to 3¼ inches, the bottom C D 1¾ inches, the vertical height from K to 5′ 2½ inches, the diameter of the foot E F 2¼ inches, and the vertical height 5′–5″ ¼-inch. Through the center of the cone draw the center line K L, and at pleasure draw the outline of the bath as shown by A J B. It is immaterial of what outline this may be, the principles that follow being applicable to any case. Thus, in the side elevation, extend the lines B C and A D until they intersect the center line at L. In similar manner extend the sides of the foot piece E D and F C until they intersect the center line at R. Now with 5′ as center and with radius equal to 5′ D or 5′ C, describe the half section C H D, which divide into equal spaces as shown by the small figures 1 to 9. From the points of division erect vertical lines meeting the base line of the bath D C at points 1, 2′, 3′, etc., to 9. From the apex L and through these points draw radial lines intersecting the outline B J A, from which horizontal lines are drawn intersecting the side of the bath B C as shown from 1 to 9. For the pattern for the body use L as center, and with L C as radius draw the arc F L^{1}. Now starting at any point, as 1, set off on F L^{1} twice the stretchout of D H C as shown by similar numbers on the arc F L^{1}. From the apex L and through the small figures draw radial lines, which intersect by arcs

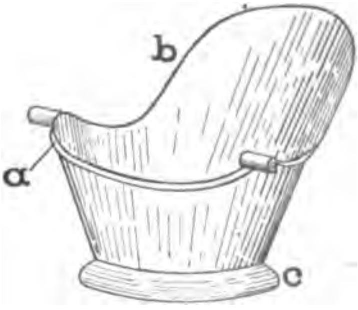


Fig. 24.

struck from L as center with radii equal to similarly numbered intersections on B C. Trace a line through points thus obtained, and L^1 M N P F will be the pattern for the body of the bath to which laps should be added at the bottom and sides for seaming.

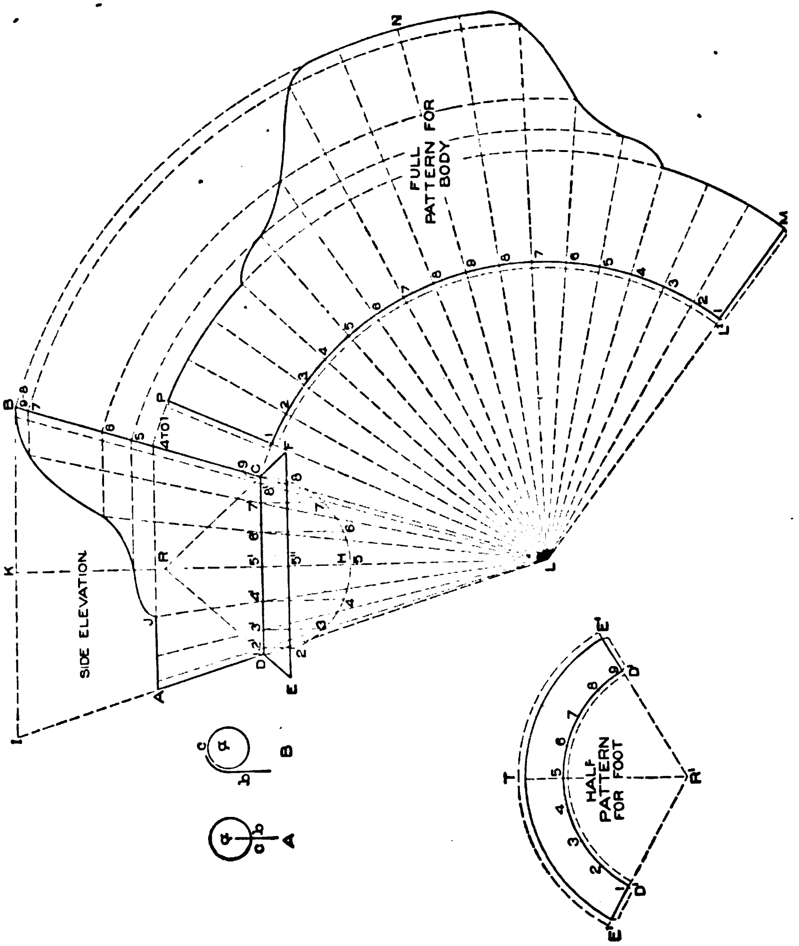


Fig. 25.

The pattern for the foot is obtained by using as radii R D and R E, and striking the pattern using R^1 as center, the half pattern being shown by E^1 T E^1 D^1 D^1, and the distance D^1 D^1 being equal to the stretchout of the half section D H C in side elevation.

It is usual to put a bead along the edges of the top of a bath as shown at *a* and *b* in Fig. 24. For this purpose tubing is sometimes used, made of brass, zinc, or copper and bent to the required shape; or zinc tubes may be rolled and soldered by hand, filled with heated white sand or hot rosin, and bent as needed. The tube or bead can be soldered to the body as shown in (A) in Fig. 25. Here *a* represents the bead, in which a slot is cut as *c*, and which is then slipped over the edge of the bath and soldered. Another method is shown in (B), in which the bath body *b* is flanged over the bead *a* and soldered clean and smooth at *c*, being then scraped and sandpapered to make a smooth joint. A wired edge is shown at *c* in Fig. 24, for which laps must be allowed as shown in Fig. 25 on the half pattern for foot.

In Fig. 26 is shown the perspective view of a bath tub; these tubs are usually made from IX tin or No. 24 galvanized iron. The bottom and side seams are locked and thoroughly soldered, while the top edge is wired with handles riveted in position as shown at A. The method used in developing these patterns will be the cone method and triangulation. In drawing this problem for practice (Fig. 27), first draw the center line W 8 in plan; and using *a* as center with a radius equal to 1½ inches draw the semicircle C-12 D. Now make the distance *a* to *b* 4 inches; and using *b* as center with a radius of 1⅝ inches draw the semicircle E-7-H. Draw lines from E to D and from C to H. D E 7 H C 12 D will be the plan of the bottom of the bath. In this case we assume that the flare between the top and bottom of the narrow end of the bath should be equal; therefore using *a* as center and with a radius equal to 1⅝ inches draw the semicircle A W B. At the upper end of the bath the flare will be unequal; therefore from *b* measure a distance on line W 8 of 1 inch and obtain *c*, which use as center, and with a radius equal to 2 inches describe the arc F 8 G. Draw lines from F to A and from B to G; and A F 8 G B W A will be the plan of the top of the bath. Now project the side elevation from the plan as shown by the dotted lines, making the slant height from I to R 2⅛ inches and from J to K 3⅛ inches; draw a line

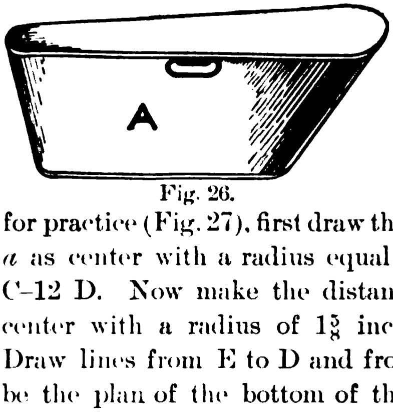


Fig. 26.

from K to R, and J K R I will be the side elevation of the bath tub. In constructing the bath in practice, seams are located at H G, F E,

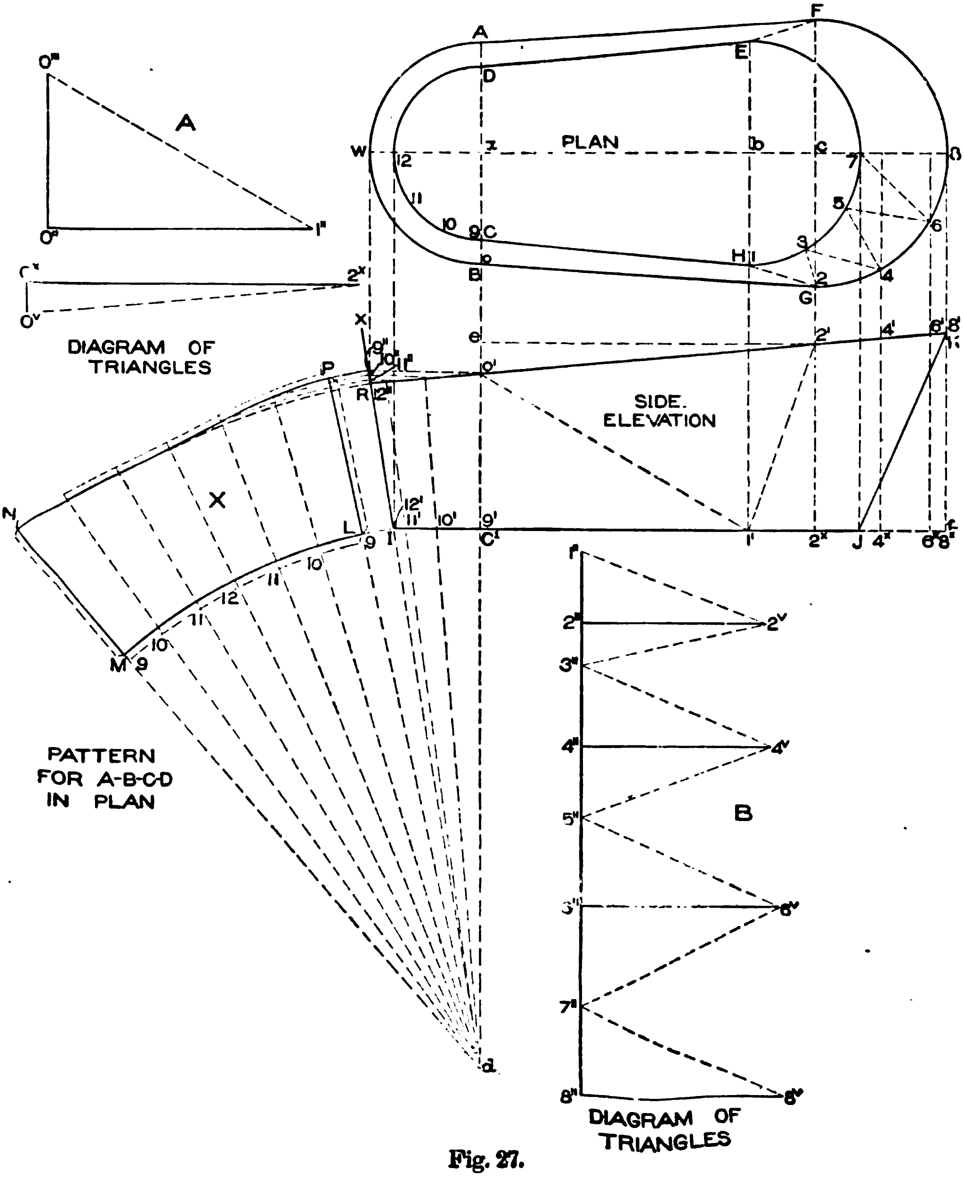


Fig. 27.

A D, and C B in plan, thus making the tub in four pieces

The lower end of the bath will be developed by the cone method as in the last two problems. From the center *a* drop a line indefinitely as shown. Extend the side R I of the side elevation until it meets the center line *a d* at *d*. Now divide the quarter circle 12–9 in plan into equal spaces as shown by the small figures 9, 10, 11, and 12, from which drop vertical lines (not shown) intersecting the bottom of the bath tub in elevation from 9′ to 12′. Then through these points from *d* draw lines intersecting the top line of the bath R K as shown, from which draw horizontal lines intersecting the side I–R extended as I X at points 9″ to 12″. Then using *d* as center and *d* I as radius, describe the arc I M, upon which place the stretchout of D 12 C in plan, as shown by similarly numbered points on L M. Through these points from *d* draw radial lines, which intersect by arcs drawn from similarly numbered intersections on I R extended, using *d* as center. Trace a line as shown, and L M N P will be the pattern for the lower end of the tub A B C D in plan. Laps should be allowed for wiring and seaming.

As the patterns for the upper end and sides will be developed by triangulation, diagrams of triangles must first be obtained, for which proceed as follows: Divide both of the quarter circles H 7 and G 8 in plan into the same number of spaces as shown respectively from 1 to 7 and from 2 to 8. Connect these numbers by dotted lines as shown from 1 to 2, 2 to 3, 3 to 4, etc. From the various points 2, 4, 6, and 8 representing the top of the bath, drop lines meeting the base line J *f* in elevation at 2^x, 4^x, 6^x, and 8^x, and cutting the top line of the bath at 2′, 4′, 6′, and 8′. Then will the dotted lines in plan represent the bases of the triangles, which will be constructed, whose altitudes are equal to the various heights in elevation. Take the various distances 1 to 2, 2 to 3, 3 to 4, 4 to 5, etc., in plan up to 8, and place them on the vertical line 1″–8″ in (B) as shown from 1″ to 2″, 2″ to 3″, 3″ to 4″, 4″ to 5″, etc., up to 8″. For example, to obtain the true length of the line 6–7 in plan, remembering that the points having even numbers represent the top line of the bath and those having uneven numbers the base line, draw at right angles to 1″–8″ in (B), from 6″, a line equal in height to 6^x–6′ in elevation, and draw a line from 6^v to 7″ in (B), which is the length desired. For the true length of 6–5 in plan it is necessary only to take this distance place it from 6″ to 5″ in (B) and draw a line from 6^v to 5″. In this way each altitude answers for two triangles. In plan draw a line from 1 to 0. Then will two more triangles be necessary, one on the line 1–0, and the other on B G or 0-2. From 2′ in elevation draw a horizontal line, as 2′ *e*, intersecting the vertical line dropped from 0 at *e*. Now take the distances 0 1 and 0 2, and place them in (A) as shown by the horizontal lines 0″–1″ and 0^x–2^x respectively. At right angles to both lines at either end draw the vertical lines 0″–0‴ and 0^x–0^v equal in height respectively to C^1 0′ and *e* 0′ in elevation. Draw in (A) lines from 2^x to 0^v and from 1″ to 0‴, which are the desired lengths. Before proceeding with the pattern, a true section must be obtained on 2′-8′ in side elevation. Take the various distances 2′ to 8′ and place them on the line 2′–8′ in Fig. 28. At right angles to 2′-8′ and through the small figures draw lines as shown. Now measuring in each and every instance from the center line in plan in Fig. 27, take the various distances to points 2, 4, and 6 and place them on similarly numbered lines in Fig. 28, measuring in each case on either side of the line 2′-8′, thus obtaining the intersections 2–4–6. A line traced through these points will be the true section on 2′-8′ in elevation in Fig. 27.

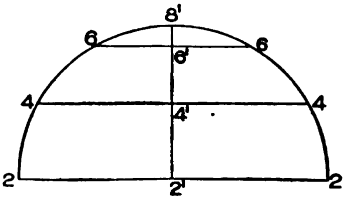


Fig. 28.

For the pattern for the upper end of the tub proceed as follows: Take the distance of 7″–8^v in (B) and place it on the vertical line 7–8 in Fig. 29. Then using 8 as center and with a radius equal to 8′–6 in Fig. 28, describe the arc 6 in Fig. 29, which intersect by an arc struck from 7 as center and with 7″–6^v in (B) in Fig. 27 as radius. Then using 7–5 in plan as radius, and 7 in Fig. 29 as center, describe the arc 5, which intersect by an arc struck from 6 as center and with 6^v–5″ in (B) in Fig. 27 as radius. Proceed in this manner, using alternately as radii first the divisions in Fig. 28, then the length of the slant lines in (B) in Fig. 27, the divisions on 7 H in plan, then again the slant lines in B, until the line 1–2 in Fig. 29 is obtained. Trace a line through points thus obtained, as shown by 2–8–7–1. Trace this opposite the line 8–7, as shown by 2′ 1′. Then will 2-8-2′-1′-7-1 be the desired pattern, to which laps must be allowed.

For the pattern for the side of the bath draw any line 9-1 in Fig. 30 equal to 9-1 in plan in Fig. 27. Now with a radius equal to 9-P in the pattern X and with 9 in Fig. 30 as a center, describe the arc 0, which intersect by an arc struck from 1 as center and with 1′-0″ in (A) in Fig. 27 as radius. Now taking a radius equal to 0^v–2^x in (A) with 0 in Fig. 30 as center, describe the arc 2, which intersect by an arc struck from 1 as center, and with 1-2 in Fig. 29 as radius. Draw lines from corner to corner in Fig. 30, which gives the desired pattern, to which laps are added for seaming and wiring.

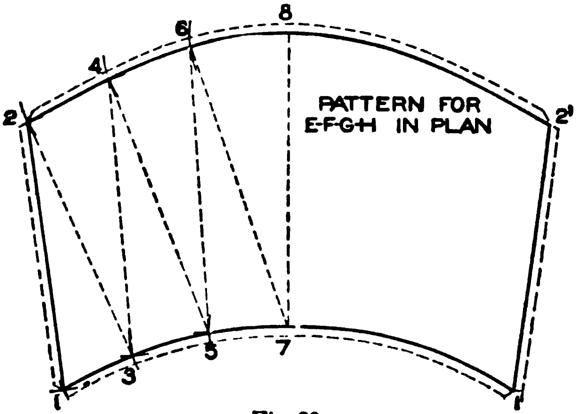


Fig. 29.

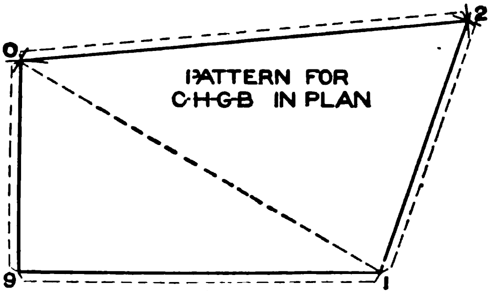


Fig. 30.

In Fig. 31 is shown a perspective view of a funnel strainer pail. These pails are usually made from IX bright tin, and the same principles as are used in the development of the pattern are applicable to similar forms, such as buckets, coal hods, chutes, etc. This problem presents an interesting study in triangulation, the principles of which have been explained in previous problems. First draw the center line O I in Fig. 32, at right angles to which draw H E and H F each equal to 1¼ inches. Make the vertical height H C 3¼ inches and C D 2 inches. Now make the vertical heights measuring from C G, to. A, and to B respectively 1¼ inches, and 1½ inches. Make the horizontal distance from C to G 2¾ inches, the diameter from G to A 1⅜ inches, and from A to B ¾-inch, and draw a line from B to C. Connect points by lines; then will A B C D E F G be the side elevation of the pail. In its proper position below F E, with J as center, draw the plan K L M N. Also in its proper position draw the section on A G as O P R S Now draw the rear elevation making G^1 U and G^1 V each equal to H E, and 1″ T and 1″–1′ each equal to C D. Project a line from B in side, intersecting the center line in rear at 4′. Then through the three points 1′ 4′ T draw the curve at pleasure, which in this case is struck from the center *a*. W Y X Z represents the opening on G A in side obtained as shown by the dotted lines but having no bearing on the patterns. Pails of this kind are usually made from two pieces, with seams at the sides, as in Fig. 31. The pattern then for the back shown by C D E H in side elevation in Fig. 32 will be obtained by the cone method, struck from the center I, the stretchout on E^1 E^2 in the pattern being obtained from the half plan. The pattern for C D E H is shown with lap and wire allowances by D^1 D^2 E^2 E^1 and needs no further explanation.

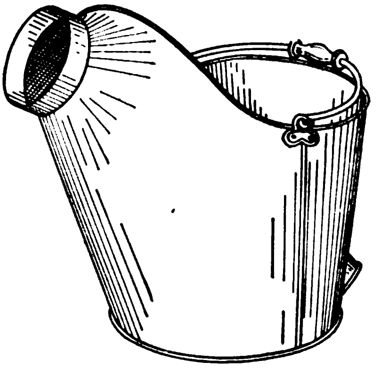


Fig. 31.

The front part of the pail shown by A B C H F G will be developed by triangulation, but before this can be done a true section must be obtained on B C, and a set of sections developed as follows: Divide one-half of 1′ 4′ T in rear elevation into equal parts as shown from 1′ to 4′, from which draw horizontal lines intersecting the line B C as shown. From these intersections lines are drawn at right angles to B C equal in length to similarly numbered lines in rear as 3′–3″, 2′–2″, and 1′–1″. Trace a line as shown, so that C 1‴ 2‴ 3‴ 4‴ will be the true half section on B C. To avoid a confusion of lines take a tracing of A B C H F G and place it as shown by similar letters in Fig. 33. Now take tracings of the half sections in Fig. 32, as H E D C, C 1‴ B, P O S, and the quarter plan N J M, and place them in Fig. 33 on similar lines on which they represent sections as shown respectively by H 9′ 8′ C, C 8 B, A 3 G, and F 9 H. Divide the half section

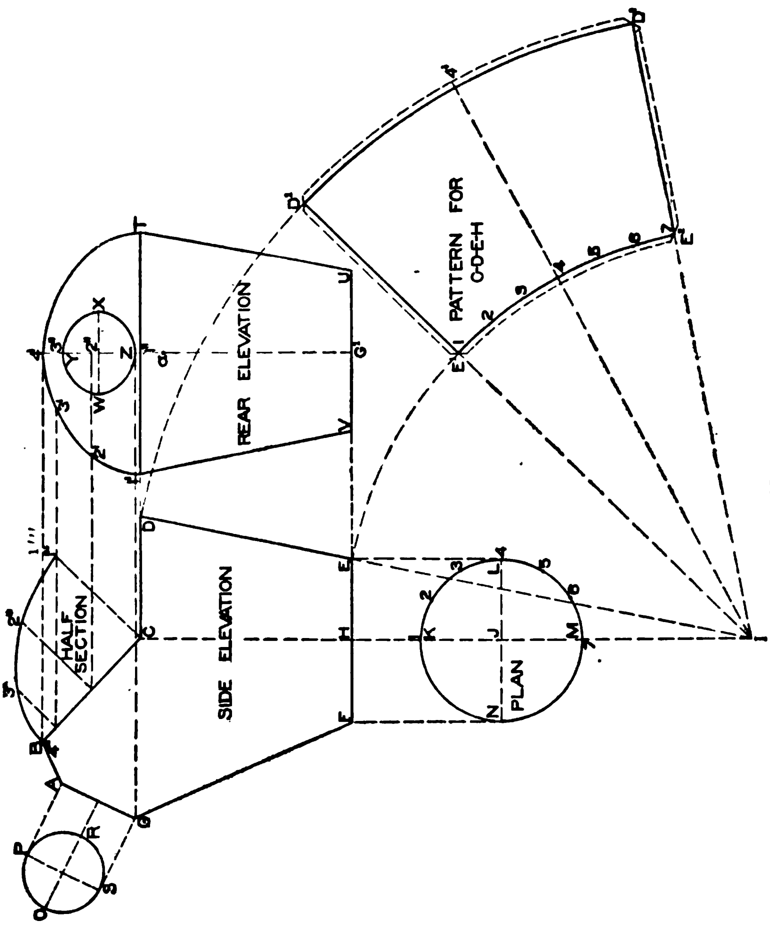
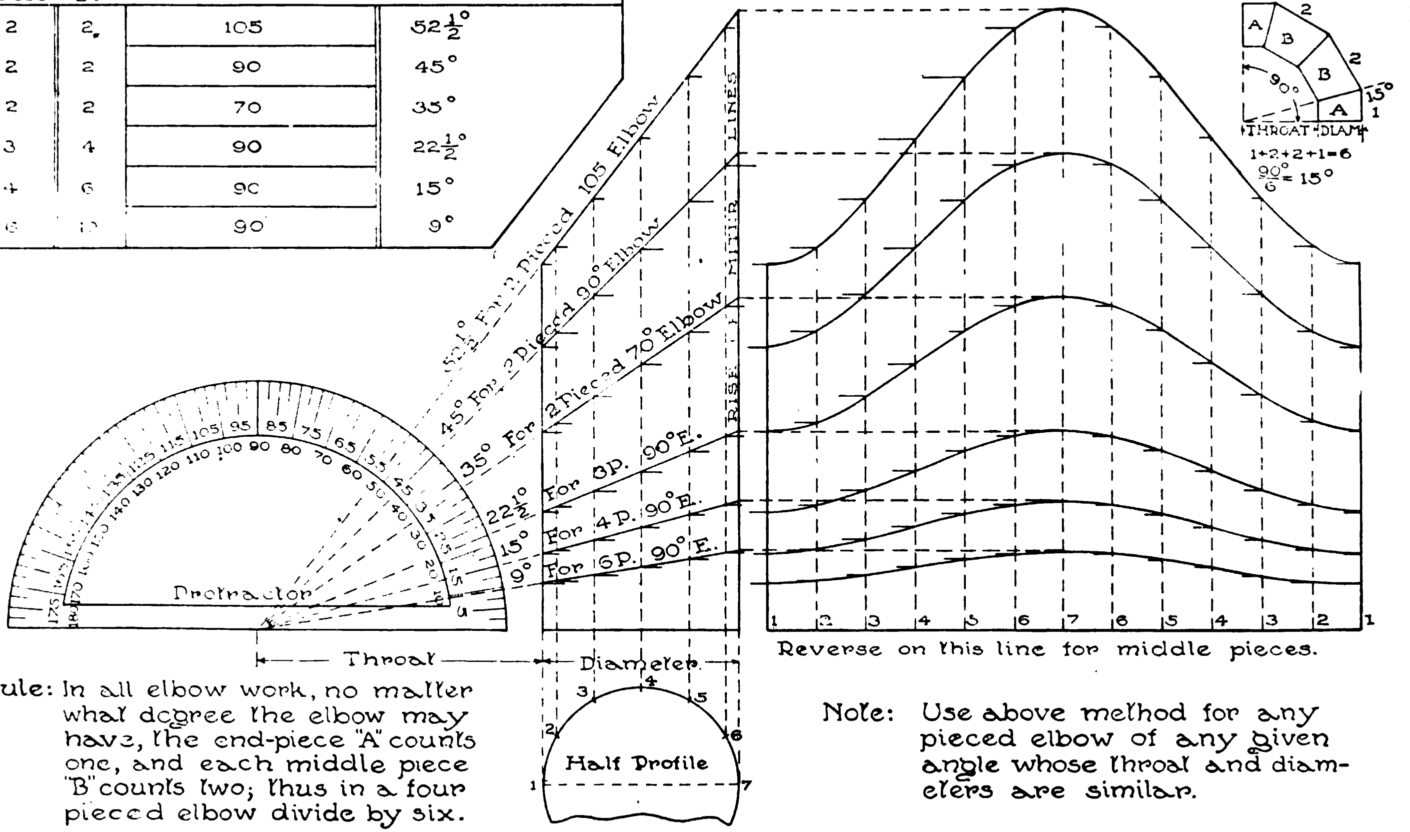


Fig. 32.

A 3 G into 6 equal parts as shown by the small figures 1 to 5. As this half section is divided into 6 parts, then must each of the sections B 8 C and F 9 H be divided into 3 parts as shown respectively from 6 to 8 and 9 to 11. As C 8′ and H 9′ are equal respectively to C 8 and H 9 they are numbered the same as shown.

PATTERNS FOR VARIOUS PIECED ELBOWS OF SIMILAR THROAT AND DIAMETER.

NO. OF PIECES	DIVIDE BY	DEGREE OF ELBOW	RISE OF MITER LINE
2	2	105	$52\frac{1}{2}$°
2	2	90	45°
2	2	70	35°
3	4	90	$22\frac{1}{2}$°
4	6	90	15°
6	10	90	9°



Reverse on this line for middle pieces.

Rule: In all elbow work, no matter what degree the elbow may have, the end-piece "A" counts one, and each middle piece "B" counts two; thus in a four pieced elbow divide by six.

Note: Use above method for any pieced elbow of any given angle whose throat and diameters are similar.

Now at right angles to G A, B C, C H, and H F, and from the various intersections contained in the sections G 3 A, B 8 C, C 8′ 9′ H, and H 9 F, draw lines intersecting the base lines of the sections G A, B C, C H, and H F at points shown from 1′ to 11′. Now draw dotted lines from B to 5′ to 6′ to 4′ to 7′ to E to C, and then from H to E to 10′ to 2′, etc until all the points are connected as shown. These dotted lines represent the bases of the sections whose altitudes are equal to similar numbers in the various sections.

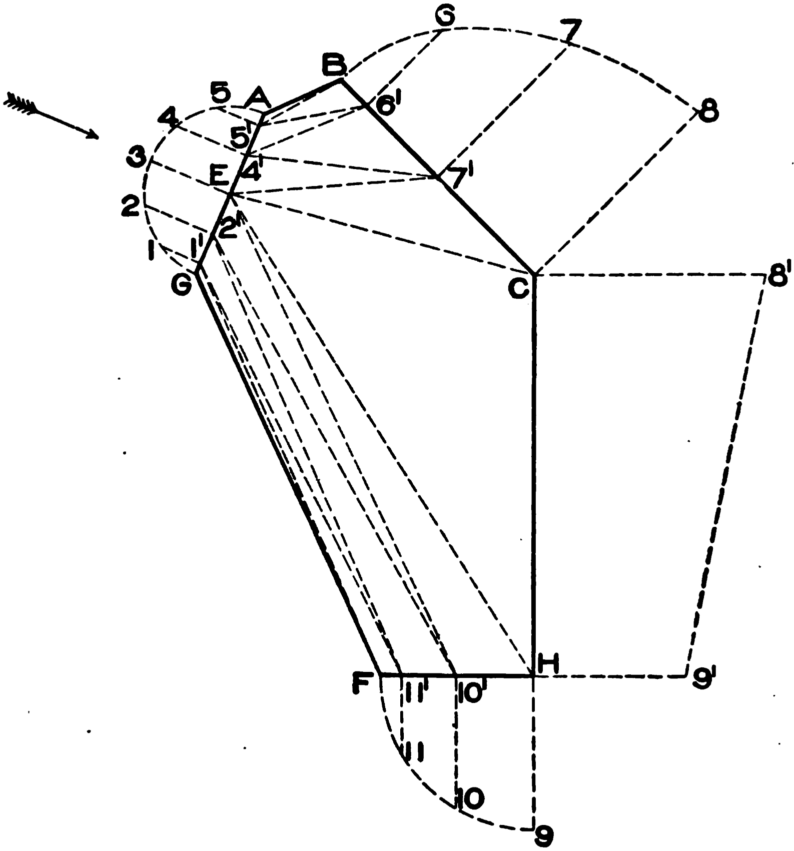


Fig. 33.

In order that the student may thoroughly understand this method of triangulation as well as similar methods that will follow in other problems, the model in Fig. 34 has been prepared, which shows a perspective of Fig. 33 with the sections bent up in their proper positions. This view is taken on the arrow line in Fig. 33, the letters and figures in both views being similar. For the true sections on the dotted lines in C E A B in Fig. 33, take the lengths of the dotted lines C E, E 7′, 7′ 4′, etc., and place them on the horizontal line in Fig. 35 as shown by similar letters and figures. From these small figures, at right angles to the horizontal line, erect the vertical heights C 8, E 3, 7′ 7, etc., equal to similar vertical heights in the sections in Fig. 33. Connect these points in Fig. 35 by dotted lines as shown, which are the desired true distances.

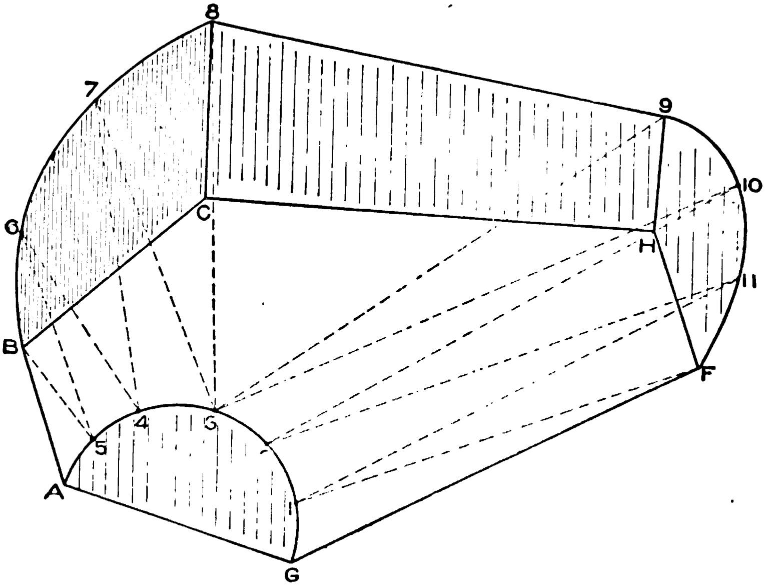


Fig. 34

In Fig. 36 are shown the true sections on dotted lines in G E H F in Fig. 33, which are obtained in precisely the same manner, the only difference being that one section is placed inside of another in Fig. 36. For the pattern proceed as is shown in Fig. 37. Draw any vertical line as G F equal to G F in Fig. 33. With radius equal to G 1 and with G in Fig. 37 as center describe the arc 1, which intersect by an arc struck from F as center and with a radius equal to F 1 in Fig. 36. Now with F 11 in Fig. 33 as radius and F in Fig. 37 as center, describe the arc 11, which is intersected by an arc struck from 1 as center and with 1–11 in Fig 36 as radius. Proceed in this manner until the line 3–9 in Fig. 37 has been obtained. Then using 8′–9′ in Fig. 33 as radius and 9 in Fig. 37 as center, describe the arc 8, which is intersected by an arc struck from 3 as center and with 3–8 in Fig. 35 as radius. Now use alternately as radii, first the divisions in B 8 C in Fig. 33, then the length of the slant lines in Fig. 35, the divisions in E 3 A in Fig. 33, and again the distances in Fig. 35, until the line B A in Fig. 37 has been obtained, which is obtained from B A in Fig. 33. Trace a line through points thus obtained in Fig. 37 as shown by A B 8 9 F G A. Trace this half pattern opposite the line G F. Then will B A G A¹ B¹ 8¹ 9¹ F 9 8 be the pattern for the front half of the pail. If for any reason the pattern is desired in one piece, then trace one half of D¹ D² E² E¹ in Fig. 32 on either side of the pattern in Fig. 37 as shown by the dotted lines 8′ D¹ E¹ 9¹ and 9 E D 8. Allow edges for wiring and seaming.

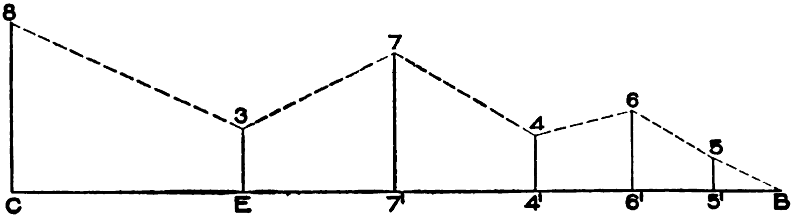


Fig. 35.

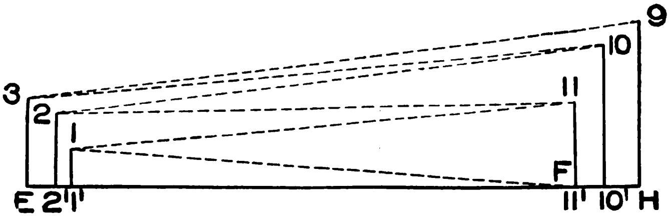


Fig. 36

Fig 38 shows the method for obtaining the pattern for an Emerson ventilator shown in Fig. 39.

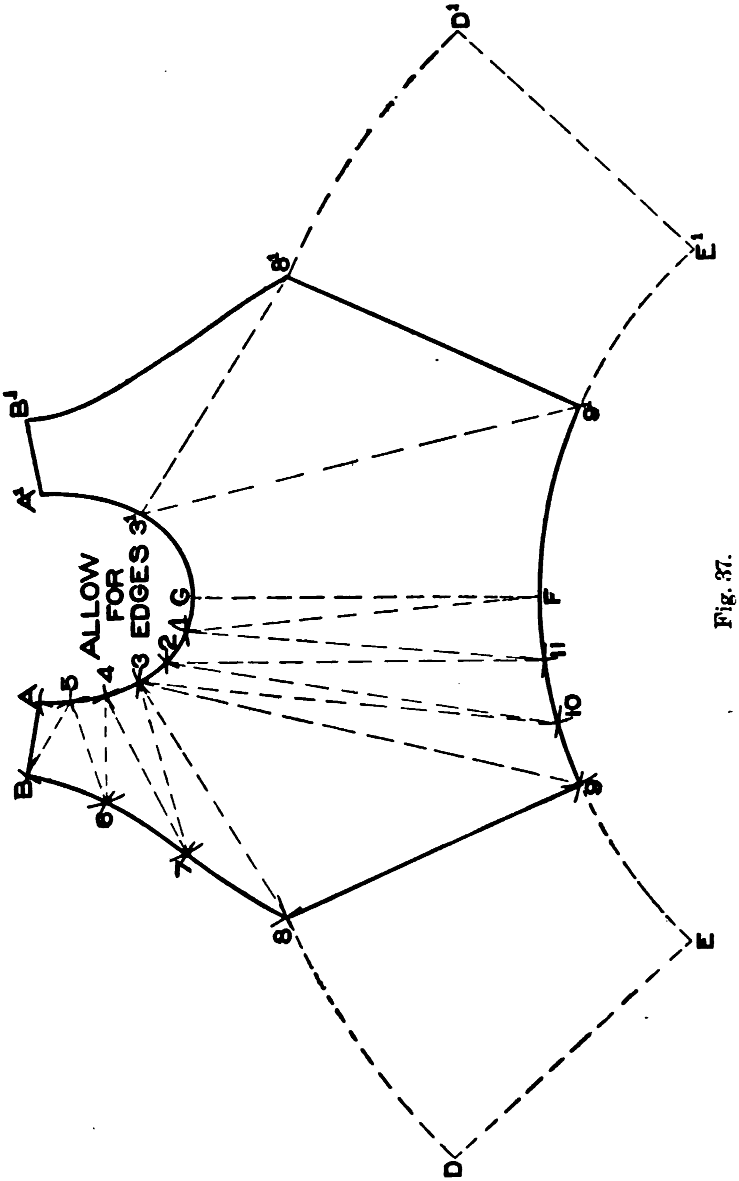


Fig. 37.

While the regular Emerson ventilator has a flat disc for a hood it is improved by placing a cone and deflector on the top as shown. To make the patterns, proceed as shown in Fig. 38. First draw the center line *a b*, on either side of which lay off

1½ inches, making the pipe A, 3 inches in diameter. The rule usually employed is to make the diameter of the lower flare and upper hood twice the diameter of the pipe. Therefore make the diameter of *s d* 6 inches. From *s* and *d*, draw a line at an angle of 45° to intersect the line of the pipe at *t* and *i*; this completes B. Measure 2 inches above the line *t i* and make *u m* the same diameter as *s d*. Draw the bevel of the deflector so that the apex will be ½ inch above the line *t i* and make the apex of the hood the same distance above *u m* as the lower apex is below it. Then draw lines as shown which complete C and D. Now with *c* as a center and radii equal to *c e* and *c d* draw the quarter circles *e f* and *d h* respectively, which represent the one-quarter pattern for the horizontal ring closing the bottom of the lower flare. For the pattern for the hood, use *l* as a center and *l m* as a radius. Now draw the arc *m m′*. Take the stretchout

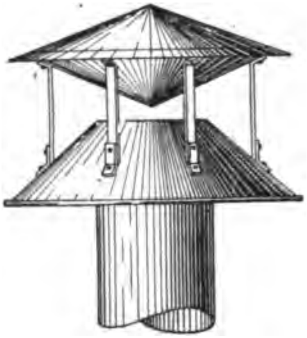


Fig. 39.

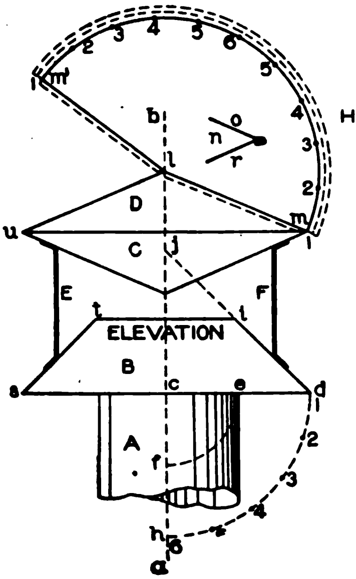


Fig. 38.

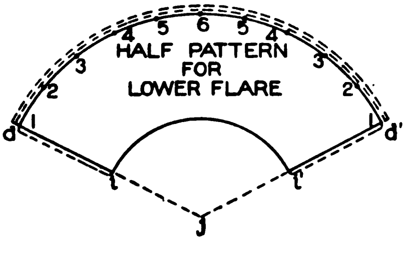


Fig. 40.

of the quarter circle 1 to 6 on *d h*, and place twice this amount on *m m'* as shown from 1–6–1. Draw a line from 1 to *l*. Then *m'* 6 *m l*, will be the half pattern for the hood. As the deflector has the same bevel as the hood, the hood pattern will also answer for the deflector.

When seaming the hood and deflector together as shown at *n*, the hood *o* is double-seamed to the deflector at *r*, which allows the water to pass over; for this reason allow a double edge on the pattern for the hood as shown, while on the deflector but a single edge is required. Edges should also be allowed on *e d h f*.

For the pattern for the lower flare, extend the line *d i* until it intersects the center line at *j*. Then with radii equal to *j i* and *j d* and with *j* in Fig. 40 as center describe the arcs *i i'* and *d d'* On one side as *d* draw a line to *j* Then set off on the arc *d d'* twice the number of spaces contained in *d h* in Fig. 38 as shown in Fig. 40. Draw a line from *d'* to i and allow edges for seaming. Then *d d' i' i* will be the half pattern for the lower flare.

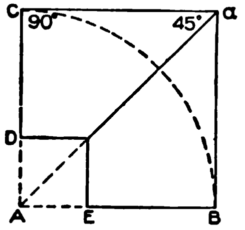


Fig. 41.

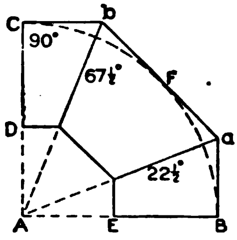


Fig. 42.

The braces or supports E and F, Fig. 38, are usually made of galvanized band iron bolted or riveted to hood and pipe. The hood D must be water tight or the water will leak into the deflector, from which it will drip from the apex inside the building.

Elbows. There is no other article in the sheet-metal worker's line, of which there are more made in practice than elbows. On this account rules will be given for constructing the rise of the miter line in elbows of any size or diameter, also for elbows whose sections are either oval, square or round, including tapering elbows Before taking up the method of obtaining the patterns, the rule will be given for obtaining the rise of the miter line for any size or number of pieces. No matter how many pieces an elbow has, they join together and form an angle of 90°. Thus when we speak of a two-pieced, three-pieced, four, five or six-pieced elbow, we understand that the right-angled elbow is made up of that number of pieces. Thus in Fig. 41 is shown a two-pieced elbow placed in the quadrant C B, which equals 90° and makes C A B a right angle. From A draw the miter line A *a* at an angle of 45° to the base line A B. Then parallel to A B and A C and tangent to the quadrant at C and B draw lines to intersect the miter line, as shown. Knowing the diameter of the pipe as C D or E B draw lines parallel to the arms of the pipe, as shown. Then C B E D will be a two-pieced elbow, whose miter line is an angle of 45°.

In a similar manner draw the quadrant B C, Fig. 42, in which it is desired to draw a three-pieced elbow. Now follow this simple rule, which is applicable for any number of pieces: Let the top piece of the elbow represent 1, also the lower piece 1, and for every piece between the top and bottom add 2. Thus in a three-pieced elbow:

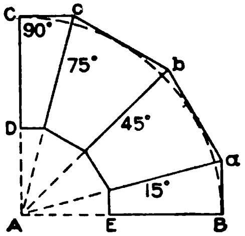


Fig. 43.

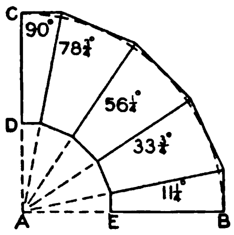


Fig. 44.

Top piece equals	1
Bottom piece equals	1
One piece between	2
Total equals	4

Now divide the quadrant of 90° by 4 which leaves 22½°. As one piece equals 22½°, draw the lower miter line A *a* at that angle to the base line A B. Then as the middle piece represents two by the above rule and equals 45°, add 45 to 22½ and draw the second miter line A *b*, at an angle of 67½° to the base line A B. Now tangent to the quadrant at C and B draw the vertical and horizontal lines shown, until they intersect the miter lines, from which intersections draw the middle line, which will be tangent to the quadrant at F. C D and B E show the diameters of the pipe, which are drawn parallel to the lines of the elbow shown.

Fig. 43 shows a four-pieced elbow, to which the same rule is applied. Thus the top and bottom piece equals 2 and the two middle pieces equal 4; total 6. Now divide the quadrant of 90° by 6. $\frac{90}{6} = 15$. Then the first miter line A *a* will equal 15°, the second A *b* 45°, the third A *c* 75°, and the vertical line A C 90°.

The last example is shown in Fig. 44, which shows a five-pieced elbow, in which the top and bottom pieces equal 2, the 3 middle pieces 6; total 8. Divide 90 by 8. $\frac{90}{8} = 11\frac{1}{4}$. Then the first miter line will equal 11¼°, the second 33¾°, the third 56¼°, and the fourth 78¾°. By using this method an elbow having any number of pieces may be laid out. When drawing these miter lines it is well to use the protractor shown in Fig. 45, which illustrates how to lay out a three-pieced elbow. From the center point A of the protractor draw lines through 22½°, and 67½°. Now set off A *a*, and the diameter of the pipe *a b*. Draw vertical lines from *a* and *b* to the miter line at *c* and *d*. Lay off similar distances from A to *a′* to *b′* and draw horizontal lines intersecting the 67½° miter line at *c′* and *d′*. Then draw the lines *d d′* and *c c′* to complete the elbow. In practice, however, it is not necessary to draw out the entire view of the elbow; all that is required is the first miter line, as will be explained in the following problems.

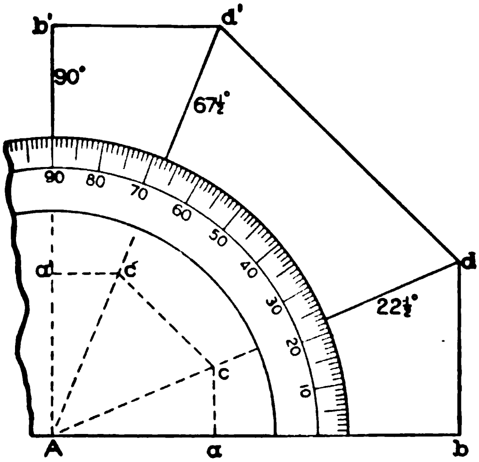


Fig. 45.

EXERCISES FOR PRACTICE.

1. Make the diameter of the pipe 1¾ inches and the distances from A to E 1½ inches in Figs. 41 to 44 inclusive.

To obtain the pattern for any elbow, using but the first miter line, proceed as follows: In Fig. 46 let A and B represent respectively a two- and three-pieced elbow for which patterns are desired. First draw a section of the elbow as shown at A in Fig. 47 which is a circle 3 inches in diameter; divide the lower half into equal spaces and number the points of division 1 to 7. Now follow the rule previously given: The top and bottom piece equals 2; then

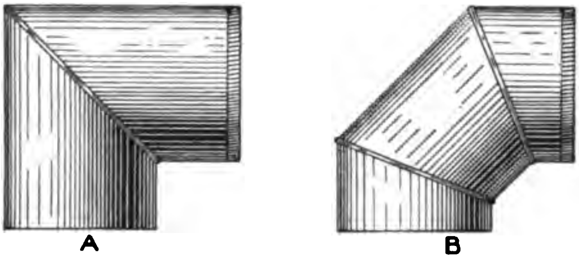


Fig. 46.

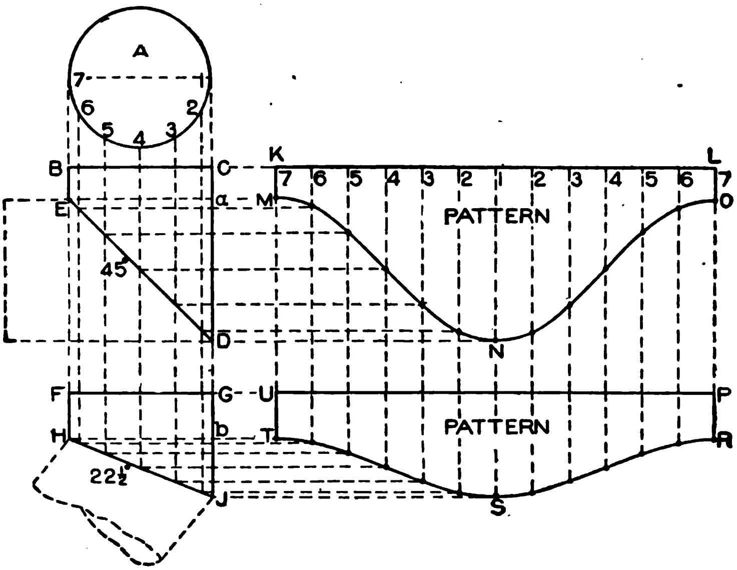


Fig. 47.

for a two-pieced elbow divide 90 by 2. In its proper position below the section A draw B C D E making E D 45°. From the various points of intersection in A drop vertical lines intersecting E D as

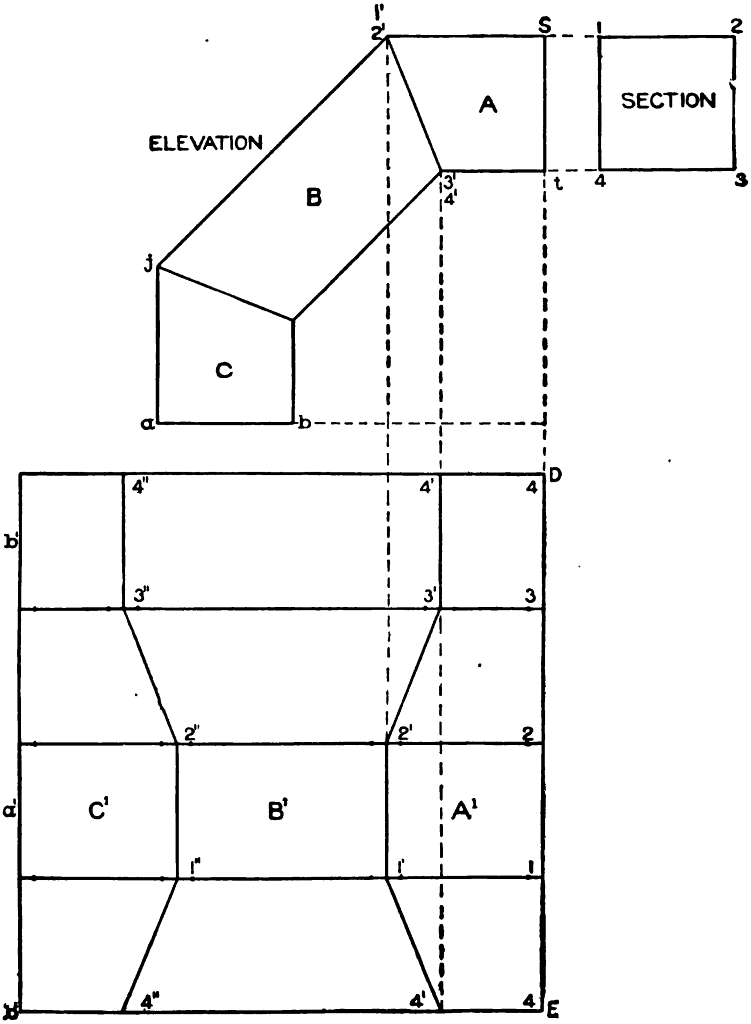


Fig. 48.

shown. In line with B C draw K L upon which place twice the number of spaces contained in the section A as shown by similar figures on K L; from these points drop perpendiculars to intersect with lines drawn from similar intersections on E D, parallel to K L. Trace a line through points shown; then K L O N M will be the pattern. To this laps must be allowed for seaming.

Now to obtain the pattern for a three-pieced elbow, follow the rule Top and bottom pieces equal 2, one middle piece equals 2; total 4. $\frac{90}{4} = 22\frac{1}{2}$. Therefore in line with the section A below the two-pieced elbow draw F G J H, making H J at an angle of $22\frac{1}{2}°$ to the line H *b*. Proceed as above using the same stretchout lines; then U P R S T will be the desired pattern. It should be understood that when the protractor is used for obtaining the angle as shown in Fig. 45, the heights *a c* and *b* d measured from the horizontal line form the basis for obtaining the heights of the middle pieces, inasmuch as they represent one-half the distance; for that reason the middle pieces count 2 when using the rule. Therefore, the distances F H and G J (Fig. 47), represent one-half of the center piece and U T S R P one-half the pattern for the center piece of a three-pieced elbow.

Fig. 48 shows how the patterns are laid into one another, to prevent waste of metal when cutting. In this example we have a three-pieced elbow whose section is 2 × 2 inches. It is to be laid out in a quadrant whose radius is 5 inches. Use the same principles for square section as for round; number the corners of the section 1 to 4. In line with S *t* draw D E upon which place the stretchout of the square section as shown by similar numbers on D E; from which draw horizontal lines which intersect lines drawn parallel to D E from the intersections 1′ 2′ and 3′ 4′ in A in elevation, thus obtaining similar points in the pattern. Then A^1 will be the pattern for A in elevation. For the pattern for B simply take the distance from 2′ to *j* and place it on the line 4 4′ extended in the pattern on either side as shown by 4′ 4″ on both sides. Now reverse the cut 4′ 2′ 4′ and obtain 4″ 2″ 4″. By measurement it will be found that 4′ 4″ is twice the length of 2′ 2 as explained in connection with Figs. 45 and 47. Make the distance from 1″ to *a′* the same as *j* to *a* in C and draw the vertical line *b′ b′* intersecting the lines 4 4″ extended on both sides. Then A^1, B^1, and C^1 will be the patterns in one piece minus the edges for seaming which must be allowed between these cuts; this would of course make the lengths b' 4", 4" 4' and 4' 4 as much longer as the laps would necessitate.

This method of cutting elbows in one piece, from one square is applicable to either round, oval or square sections.

In Figs. 49 and 50 are shown three-pieced elbows such as are

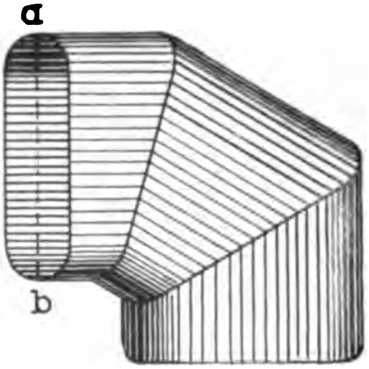


Fig. 49.

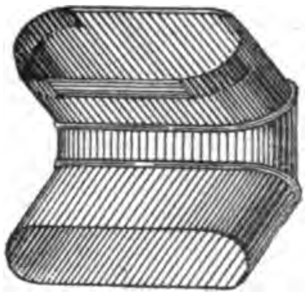


Fig. 50.

used in furnace-pipe work and are usually made from bright tin. Note the difference in the position of the sections of the two elbows. In Fig. 49 *a b* is in a vertical position, while in Fig. 50 it is in a horizontal position. In obtaining the patterns the same rule is employed as in previous problems, care being taken when developing the patterns for Fig. 49 that the section be placed as in Fig. 51 at A; and when developing the patterns for Fig. 50, that the section be placed as shown at A in Fig. 52.

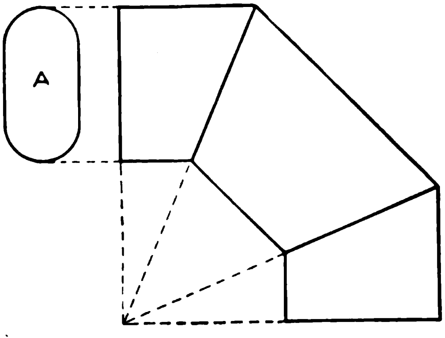


Fig. 51.

Fig. 53 shows a tapering two-pieced elbow, round in section. The method here shown is short and while not strictly accurate, gives good results. It has been shown in previous problems on Intersections and Developments that an oblique section through the opposite sides of a cone is a true ellipse. Bearing this in mind it is evident that if the frustum of the cone H I O N, Fig. 54, were a solid and cut obliquely by the plane J K and the several parts placed side by side, both would present true ellipses of exactly the same size, and if the two parts were placed together again turning the upper piece half-way around as shown by J W M K, the edges of the two pieces from J to K would exactly coincide. Taking advantage of this fact, it is necessary only to ascertain the angle of the line J K, to produce the required angle, between the two pieces of the elbow, both of which have an equal flare. The angle of the miter line, or the line which cuts the cone in two parts, must be found accurately so that when joined together an elbow will be formed having the desired angle on the line of its axis.

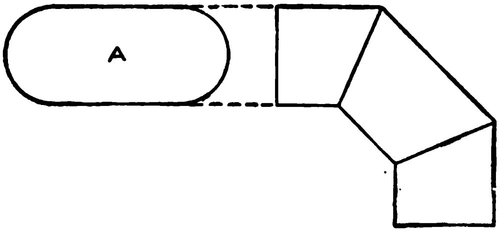


Fig. 52.

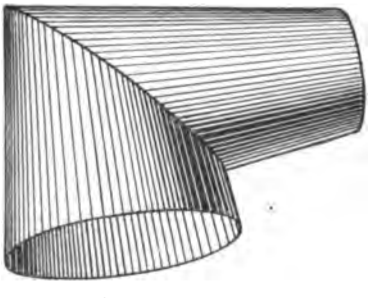


Fig. 53.

Therefore draw any vertical line as A B. With C as a center describe the plan of the desired diameter as shown by E D F B. At right angles to A B draw the bottom line of the elbow H I equal to E F, or in this case, 3 inches. Measuring from the line H I on the line A B the height of the frustum is 5 inches. Through X′ draw the upper diameter O N, $1\frac{1}{2}$ inches. Extend the contour lines of the frustum until they intersect the center line at L. Divide the half plan E D F into a number of equal parts as shown; from these points erect lines intersecting the base line H I from which draw lines to the apex L. As the elbow is to be in two pieces, and the axis at right angles, draw the angle T R S, bisect it at U and draw the line R V. No matter what the angle of the elbow, use this method. Now establish the point J at some convenient point on the cone, and from J, parallel to R V, draw the miter line J K intersecting the radial lines drawn through the cone; from these points and at right angles to the center line A B draw lines intersecting the side of the cone J H from 1 to 7. If it is

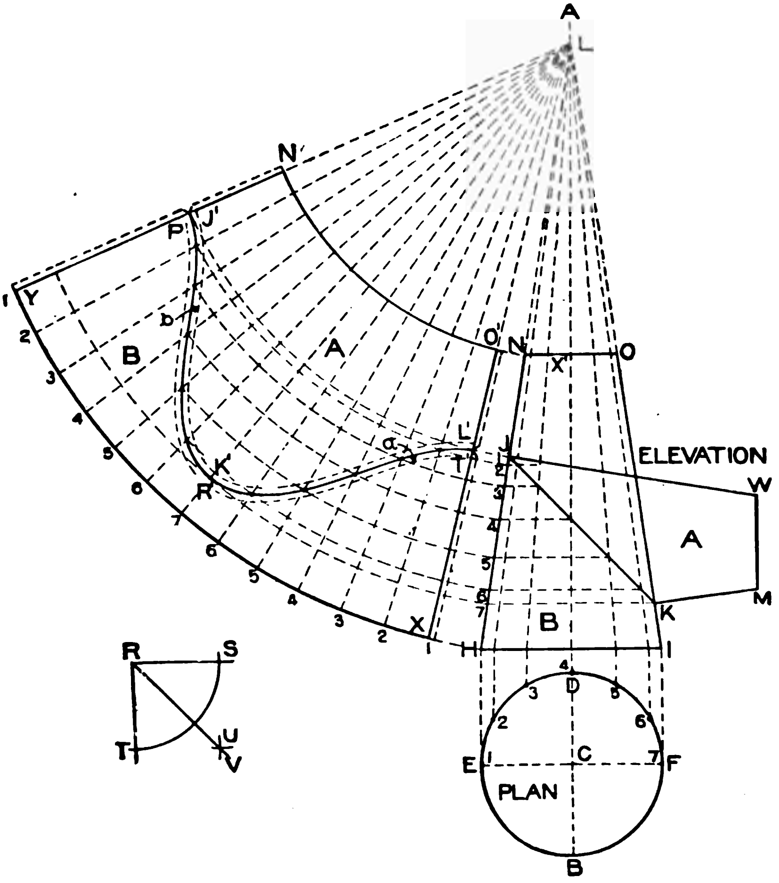


Fig. 54.

desired to know how the side of the tapering elbow would look, take a tracing of N O K J, reverse it and place it as shown by J W M K.

For the pattern proceed as follows: With L as a center and L H as a radius describe the arc 1 1. Starting from 1 set off on this arc twice the stretchout of 1 4 7 in plan, as shown by similar figures on 1 1, from which draw radial lines to the apex L. Again using L as center with radii equal to L N, L 1, L 2 to L 7, draw arcs as shown intersecting radial lines having similar numbers. Through these intersections draw the line J′ L′. Then O′ N′ J′ K′ L′ or A will be the pattern for the upper arm (A) in elevation, and P′ R′ T′ X Y or B the pattern for the lower arm (B) in elevation.

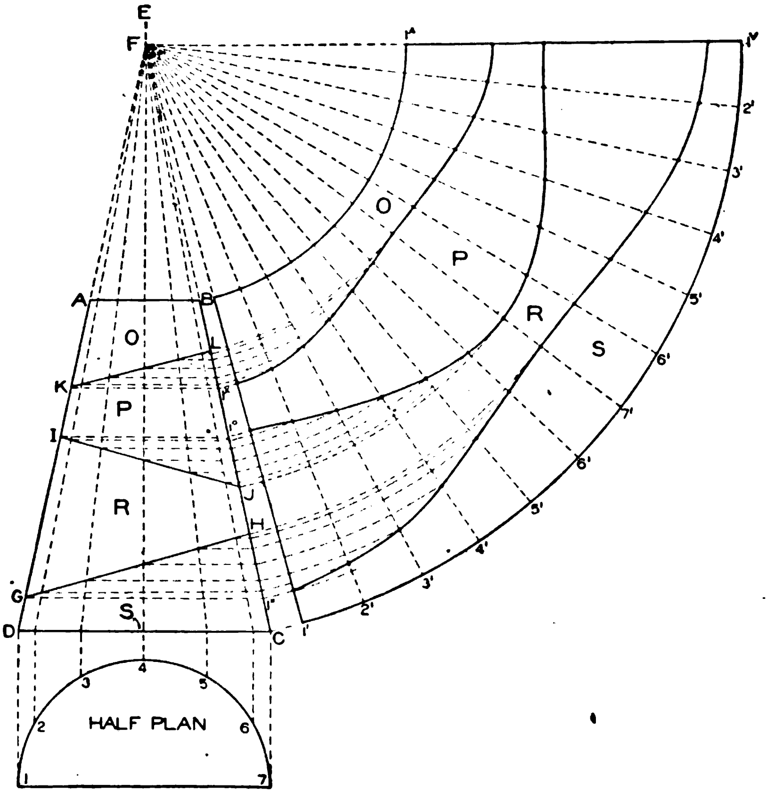


Fig. 55.

The pattern should be developed full size in practice and then pricked from the paper on to the sheet metal, drawing the two patterns as far apart as to admit allowing an edge to A at *a*; also an edge at *b* to B for seaming.

When a pattern is to contain more than two pieces the method of constructing the miter lines in the elevation of the cone is slightly different as shown in Fig. 55. Assume the bottom to be 3 inches in diameter and the top $1\frac{1}{4}$ inches. Let the vertical height be 4 inches. In this problem, as in the preceding, the various pieces necessary to form the elbow are cut from one cone whose dimensions must be determined from the dimensions of the required elbow. The first step is to determine the miter lines, which can be done the same as if regular pieced elbows were being developed. As the elbow is to consist of four pieces in 90°, follow the rule given in connection with elbow drafting. The top and bottom piece equal 2; the two middle pieces equal 4; total 6. $\frac{90}{6} = 15$ Lay off A B C D according to the dimensions given, and draw the half plan below D C; divide it into equal parts as shown. From the points of division erect perpendiculars intersecting D C, from which draw lines meeting the center line E 4 at F.

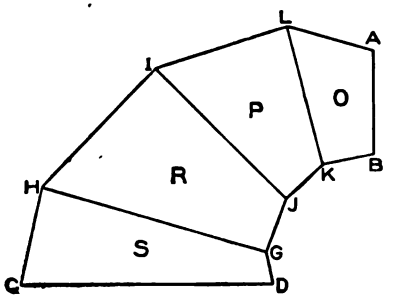


Fig. 56.

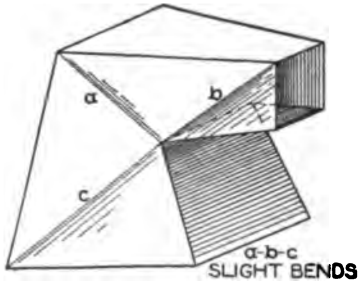


Fig. 57.

We assume that the amount of rise and projection of the elbow are not specified, excepting that the lines of axis will be at right angles. Knowing the angle of the miter line, it becomes a matter of judgment upon the part of the pattern draftsman, what length shall be given to each of the pieces composing the elbow. Therefore establish the points G, I and K, making D G, G I, I K and K A $\frac{1}{2}$, $1\frac{7}{8}$, $\frac{3}{4}$ and 1 inch respectively. From G, I and K draw the horizontal lines G $1''$, I 1° and K 1^{x}. To each of these lines draw the lines G H, I J and K L respectively at an angle of 15° intersecting the radial lines in the cone as shown. From these intersections draw horizontal lines cutting the side of the cone. Then using F as a center, obtain the various patterns O, P, R and S in the manner already explained.

In Fig. 56 is shown a side view of the elbow, resulting from preceding operations; while it can be drawn from dimensions obtained in Fig. 55, it would be impossible to draw it without first having these dimensions.

In Fig. 57 is shown a perspective view of a tapering square elbow of square section in two pieces. This elbow may have any given taper. This problem will be developed by triangulation and parallel lines; it is an interesting study in projections as well as in developments. First draw the elevation of the elbow in Fig. 58 making 1–6 equal to 3½ inches, the vertical height 1–2, 4½ inches, and 6–5, 2½ inches; the projection between 1 and 2 should be ⅝ inch and between 5 and 6, ⅜ inch. Make the horizontal distance from 5 to 4, 2 inches, and the rise at 4 from the horizontal line ¼ inch, and the vertical distance from 4 to 3, 1¼ inches. Then draw a line from 3 to 2 to complete the elevation.

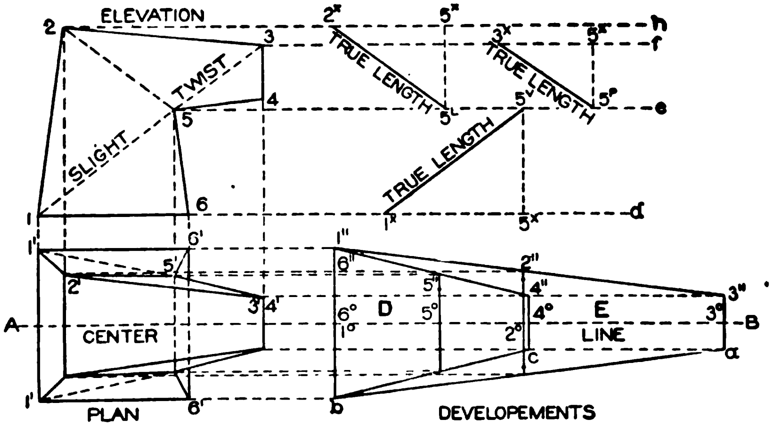


Fig. 58.

In its proper position below the line 1–6, draw the plan on that line, as shown by 1′ 1′ 6′ 6′. Through this line draw the center line A B. As the elbow should have a true taper from 1 to 3 and from 4 to 6, we may develop the patterns for the top and bottom pieces first and then from these construct the plan. Therefore, take the distances from 1 to 2 to 3 and from 4 to 5 to 6 in elevation and place them on the line A B in plan as shown respectively from 1° to 2° to 3° and from 4° to 5° to 6°; through these points draw vertical lines as shown. While the full developments

E and D are shown we shall deal with but one-half in the explanation which follows. As the elbow is to have the same taper on either side, take the half distance of the bottom of the elbow 1–6 and place it as shown from 1°–6° to 1″–6″, and the half width of the top of the elbow 3–4 and place it as shown from 3° to 3″ and 4° to 4″. Then draw lines from 3″ to 1″ intersecting the bend 2° at 2″, and a line from 4″ to 6″ intersecting the bend 5° at 5″. Trace these points on the opposite side of the line A B. Then 1″ 3″ *a b* will be the pattern for the top of the elbow and 6″ 4″ *c b* the pattern for the bottom. From these various points of intersection draw horizontal lines to the plan, and intersect them by lines drawn from similarly numbered points in the elevation at right angles to A B in plan. Draw lines through the points thus obtained in plan as shown by 1′, 2′, 3′, 4′, 5′ and 6′ which will represent the half plan view. For the completed plan, trace these lines opposite the line A B as shown. It will be noticed that the line 3–4 in elevation is perpendicular as shown by 3′ 4′ in plan while the points 2′ and 5′ project from it, showing that the piece 2–3–4–5 in elevation must be slightly twisted along the line 5–3 when forming the elbow. Similarly slight bends will be required along the lines 1–5 and 5–2.

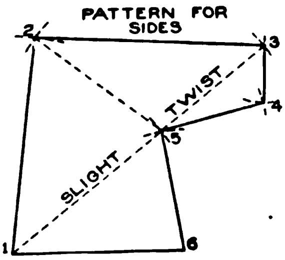


Fig. 59.

It will now be necessary to obtain the true lengths or a diagram of triangles on the lines 1–5, 5–2 and 5–3. Connect similar numbers in plan as shown from 1′ to 5′, 5′ to 2′ and 5′ to 3′, the last two lines being already shown. From similar points in elevation draw horizontal lines as shown by 2–*h*, 3–*f*, 5–*e* and 6–*d*. Take the distances from 1′ to 5′, 5′ to 2′ and 5′ to 3′ in plan and place them on one of the lines having a similar number in elevation, as shown respectively by 1^x 5^x, 5^x 2^x and 5^x 3^x. From the points marked 5^x draw vertical lines intersecting the horizontal line drawn from 5 at 5^v, 5^r and 5^p respectively. Now draw the true lengths 1^x 5^v, 2^x 5^r, and 3^x 5^p. For the pattern draw any line as 1–6 in Fig. 59 equal to 1–6 in Fig. 58. Now with 6″ 5″ in D as a radius and 6 in Fig. 59 as a center, describe the arc 5 which is intersected by an arc struck from 1 as a center and the true length

1^x 5^v in Fig. 58 as radius. Then using the true length 5^L 2^x as radius and 5 in Fig. 59 as center, describe the arc 2, which is intersected by an arc struck from 1 as center and 1″ 2″ in E in Fig. 58 as radius. Using the true length 5^p 3^x as radius and 5 in Fig. 59 as center, describe the arc 3, and intersect it by an arc struck from 2 as center and 2″ 3″ in E in Fig. 58 as a radius. Now with 5″ 4″ in D as a radius and 5 in Fig. 59 as a center, describe tht arc 4, and intersect it by an arc struck from 3 as center and 3-4 in the elevation in Fig. 58 as a radius. Draw lines from point to point in Fig. 59 to complete the pattern. Laps should be allowed on all patterns, for seaming. Slight bends will take place as shown on the pattern, also as is shown by *a b* and *c* in Fig. 57. If the joint is to be on the line 2–5 in elevation in Fig. 58, the necessary pieces can be joined together.

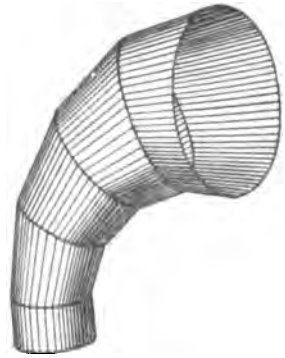


Fig. 60.

In Fig. 60 is shown a perspective view of a five-piece tapering elbow, having a round base and an elliptical top. This form is generally known as a ***ship ventilator.*** The principles shown in this problem are applicable to any form or shape no matter what the respective profiles may be at the base or top. The first step is to draw a correct side view of the elbow as shown in Fig. 61. The outline A B C D E F can be drawn at pleasure, but for practice, dimensions are given. First draw the vertical line A F equal to 4½ inches. On the same line extend measure down 1¼ inches to *f* and draw the horizontal line H B. From *f* set off a distance of 1¼ inches at G, and using G as a center and G F as a radius describe the arc F E intersecting H B at E, from which draw the vertical line E D equal to 1 inch. Draw D C equal to 1¾ inches, then draw C B. From B lay off 5¾ inches, and using this point (H) as a center and H B as a radius describe the arc B A. The portion shown B E D C is a straight piece of pipe whose section is shown by I J K L. Now divide the two arcs B A and E F into the same number of parts that the elbow is to have pieces (in this case four) and draw the lines of joint or miter lines as shown by U V, etc.

Bisect each one of the joint lines and obtain the points *a b c d* and *e*. Then A B C D E F will be the side view.

The patterns will be developed by triangulation, but before this can be done, true sections must be obtained on all of the lines in side elevation. The true sections on the lines B E and C D are shown by I J K L. The length of the sections are shown by the joint lines, but the width must be obtained from a front outline of the elbow, which is constructed as follows: In its proper relation to the side elevation, draw the center line M R upon which draw

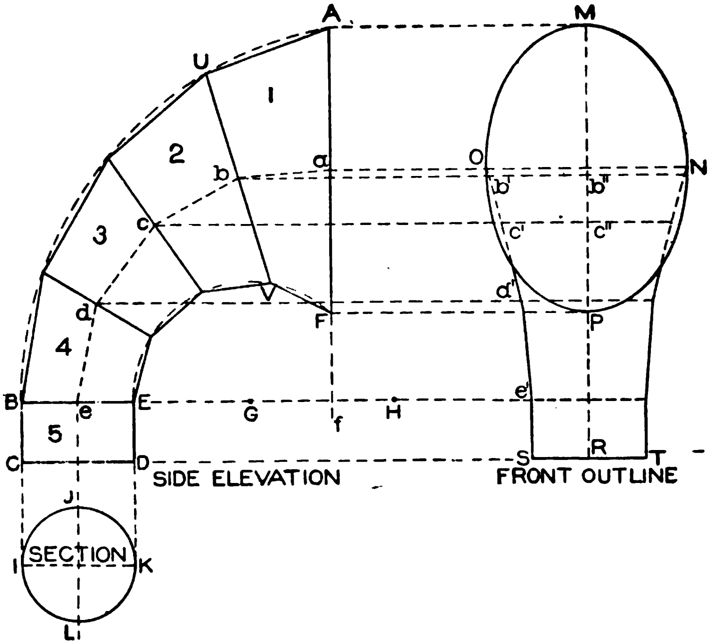


Fig. 61.

the ellipse M N O P (by methods already given in Mechanical Drawing) which represents the section on A F in side. Take half the diameter I K in section and place it on either side of the center line M R as R T or R S. Then draw the outline O S and T N in a convenient location. While this line is drawn at will, it should be understood that when once drawn, it becomes a fixed line. Now from the various intersections *a b c d* and *e* in the side elevation, draw lines through and intersecting the front outline as shown on one side by O, *b'*, *c'*, *d'* and *e'*. Then these distances will represent the widths of the sections shown by similar letters in side. For example, the method will be shown for obtaining the true section on U V, and the pattern for piece 1 in side elevation. To avoid a confusion of lines take a tracing of A F V U and place it as shown by 1, 13, 12, O in Fig. 62. On 1–13 place the half profile M N P of Fig. 61. Bisect O–12 in Fig. 62 and obtain the point 6; at a right angle to O–12 from 6 draw the line 6 6′ equal to *b′ b″* in front outline in Fig. 61. Then through the three points O, 6′ and 12 in Fig. 62, draw the semi-ellipse, which will represent the half section on U V. The other sections on the joint lines in side elevation are obtained in the same manner.

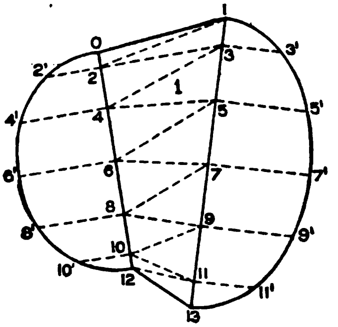


Fig. 62.

If the sections were required for piece 2 in side it would be necessary to use only O 6′ 12 in Fig. 62 and place it on U V in Fig. 61, and on a perpendicular line erected from *c*, place the width *c′ c″* shown in front and through the three points obtained again draw the semi-elliptical profile or section. Now divide the two half sections (Fig. 62) into equal parts as shown by the small figures, from which at right angles to 1–13 and O–12 draw lines intersecting these base lines from 1–13. Connect opposite points as 1 to 2 to 3 to 4 to 5, etc., to 12. Then these lines will represent

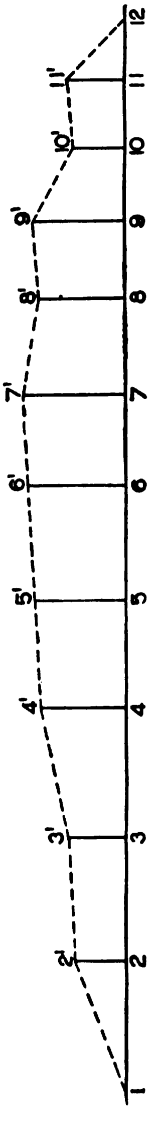


Fig. 63.

the bases of sections whose altitudes are equal to the heights in the half section. For these heights proceed as follows:

Take the various lengths from 1 to 2, 2 to 3, 3 to 4, 4 to 5, etc., to 11 to 12 and place them on the horizontal line in Fig. 63 as shown by similar figures; from these points erect vertical lines equal in height to similar figures, in the half section in Fig. 62 as shown by similar figures in Fig. 63. For example: Take the distance from 7 to 8 in Fig. 62 and place it as shown from 7 to 8 in Fig. 63 and erect vertical lines 7–7′, and 8–8′ equal to 7–7′ and 8–8′ in Fig. 62. Draw a line from 7′ to 8′ in Fig. 63 which is the true length on 7–8 in Fig. 62. For the pattern take the distance of 1–O and place it as shown by 1–O in Fig. 64. Now using O as a center and O 2′ in Fig. 62 as a radius, describe the arc 2 in Fig. 64 and intersect it by an arc struck from 1 as a center with 1–2′ in Fig. 63 as a radius. Now with 1–3′ in Fig. 62 as a radius and 1 in Fig. 64 as a center, describe the arc 3, and intersect it by an arc struck from 2 as center and 2′–3′ in Fig. 63 as a radius. Proceed thus, using alternately as radii, first the divisions in O–6′–12 in Fig. 62, then the proper line in Fig. 63, the divisions in 1–7′–13 in Fig. 62 and again the proper line in Fig. 63, until the line 12–13 in Fig. 64 is obtained, which equals 12–13 in Fig. 62. In this manner all of the sections are obtained, to which laps must be allowed for wiring and seaming.

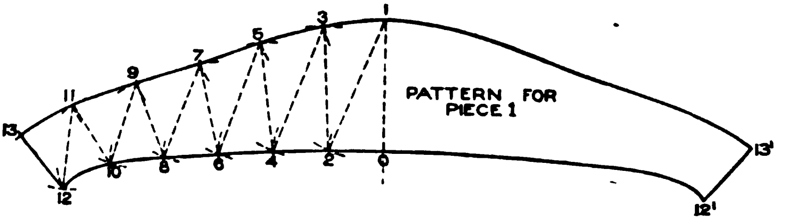


Fig. 64.

TABLES.

The following tables will be found convenient for the Sheet-Metal Worker:

TABLES	PAGE.
Weight of Cast Iron, Wrought Iron, Copper, Lead, Brass and Zinc	62
Sheet Copper	63
Sheet Zinc	64
Standard Gauge for Sheet Iron and Steel	65
Weights of Flat Rolled Iron	66–71
Square and Round Iron Bars	72-73
Angles and Tees	74

WEIGHT OF A SQUARE FOOT OF CAST AND WROUGHT IRON, COPPER, LEAD, BRASS AND ZINC.

FROM $\frac{1}{16}$ INCH TO ONE INCH IN THICKNESS.

THICKNESS.	CAST IRON.	WROUGHT IRON.	COPPER.	LEAD.	BRASS.	ZINC.
Inch.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1-16	2.346	2.517	2.89	3.691	2.675	2.34
1-8	4.693	5.035	5.781	7.382	5.35	4.68
3-16	7.039	7.552	8.672	11.074	8.025	7.02
1-4	9.386	10.07	11.562	14.765	10.7	9.36
5-16	11.733	12.588	14.453	18.456	13.375	11.7
3-8	14.079	15.106	17.344	22.148	16.05	14.04
7-16	16.426	17.623	20.234	25.839	18.725	16.34
1-2	18.773	20.141	23.125	29.53	21.4	18.72
9-16	21.119	22.659	26.016	33.222	24.075	
5-8	23.466	25.176	28.906	36.923	26.75	
11-16	25.812	27.694	31.797	40.604	29.425	
3-4	28.159	30.211	34.688	44.296	32.1	
13-16	30.505	32.729	37.578	47.987		
7-8	32.852	35.247	40.469	51.678		
15-16	35.199	37.764	43.359	55.37		
1	37.545	40.282	46.25	59.061		

NOTE.—The wrought iron and the copper weights are those of hard-rolled plates.

SHEET COPPER.

Official table adopted by the Association of Copper Manufacturers of the United States. Rolled copper has specific gravity of 8.93. One cubic foot weighs 558.125 pounds. One square foot, one inch thick, weighs 46.51 pounds.

Stubs' Gauge, (nearest number).	Thickness in decimal parts of an inch.	Ounces per sq. ft.	Sheets 14″ x 48″ Weight in pounds.	Sheets 24″ x 48″ Weight in pounds.	Sheets 30″ x 60″ Weight in pounds.	Sheets 36″ x 72″ Weight in pounds.	Sheets 48″ x 72″ Weight in pounds.
35	.00537	4	1.16	2	3.12	4.50	6
33	.00806	6	1.75	3	4.68	6.75	9
31	.0107	8	2.33	4	6.25	9	12
29	.0134	10	2.91	5	7.81	11.25	15
27	.0161	12	3.50	6	9.37	13.50	18
26	.0188	14	4.08	7	10.93	15.75	21
24	.0215	16	4.66	8	12.50	18	24
23	.0242	18	5.25	9	14.06	20.25	27
22	.0269	20	5.83	10	15.62	22.50	30
21	.0322	24	7	12	18.75	27	36
19	.0430	32	9.33	16	25	36	48
18	.0538	40	11.66	20	31.25	45	60
16	.0645	48	14	24	37.50	54	72
15	.0754	56	16.33	28	43.75	63	84
14	.0860	64	18.66	32	50	72	96
13	.095	70	....	35	55	79	105
12	.109	81	....	40½	63	91	122
11	.120	89	....	44½	70	100	134
10	.134	100	....	50	78	112	150
9	.148	110	....	55	86	124	165
8	.165	123	....	61	96	138	184
7	.180	134	....	67	105	151	201
6	.203	151	....	75½	118	170	227
5	.220	164	....	82	128	184	246
4	.238	177	....	88½	138	199	266
3	.259	193	....	96	151	217	289
2	.284	211	....	105½	165	238	317
1	.300	223	....	111½	174	251	335
0	.340	253	....	126½	198	285	380

SHEET ZINC.

Numbers		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Weight per sq. foot		.30	.37	.45	.52	.60	.67	.75	.90	1.05	1.20	1.35	1.50	1.68	1.87	2.06	2.25	2.62	3.00	3.37
Approximate thickness in inches		.008	.010	.012	.014	.016	.018	.020	.024	.028	.032	.036	.040	.045	.050	.055	.060	.070	.080	.090
Size of sheet.	Sq. ft. per sheet.	APPROXIMATE WEIGHT PER SHEET.																		
24 x 84 in.	14.	4.2	5.2	6.3	7.3	8.4	9.4	10.5	12.6	14.7	16.8	18.9	21.	23.5	26.2	28.9	31.5	36.7	42.	47.2
26 x 84	15.2	4.6	5.6	6.9	7.9	9.1	10.2	11.4	13.7	16.	18.3	20.5	22.8	25.6	28.4	31.3	34.2	39.9	45.6	51.2
28 x 84	16.3	4.9	6.	7.4	8.5	9.8	10.9	12.2	14.7	17.1	19.6	22.	24.5	27.4	30.5	33.6	36.7	42.7	48.9	54.9
30 x 84	17.5	5.3	6.5	7.9	9.1	10.5	11.8	13.2	15.8	18.4	21.	23.6	26.2	29.4	32.8	36.1	39.4	45.8	52.5	59.
32 x 84	18.7	5.6	6.9	8.4	9.7	11.2	12.6	14.1	16.9	19.7	22.5	25.3	32.8	31.4	35.	38.5	42.	49.	56.1	63.
34 x 84	19.9	6.0	7.4	9.	10.4	12.	13.4	15.	18.	20.9	23.9	26.9	29.9	33.4	37.2	41.	44.8	52.2	59.7	67.
36 x 84	21.	6.3	7.8	9.5	10.9	12.6	14.1	15.8	18.9	22.	25.2	28.4	31.5	35.3	39.3	43.3	47.2	55.	63.	70.8
36 x 96	24.	7.2	8.9	10.8	12.5	14.4	16.1	18.	21.6	25.2	28.8	32.4	36.	40.3	44.9	49.5	54.	62.8	72.	80.9
36 x 108	27.	8.1	10.	12.2	14.1	16.2	18.1	20.3	24.3	28.4	32.4	36.5	40.5	45.4	50.5	55.6	60.7	70.7	81.	91.
40 x 84	23.4	7.	8.7	10.6	12.2	14.1	15.7	17.6	21.	24.6	28.1	31.6	35.1	39.3	43.8	48.2	52.6	61.3	70.2	78.8
40 x 96	26.8	8.	9.9	12.1	14.	16.1	18.	20.1	24.1	28.1	32.2	36.2	40.2	45.	50.1	55.2	60.3	70.2	80.4	90.3
44 x 84	25.7	7.7	9.5	11.6	13.4	15.4	17.2	19.3	23.1	27.	30.8	34.7	38.6	43.2	48.1	53.	57.8	67.4	77.1	86.6
46 x 90	28.7	8.6	10.6	12.9	14.9	17.2	19.2	21.5	25.8	30.1	34.4	38.7	43.	48.2	53.7	59.1	64.6	75.2	86.1	96.7
48 x 84	28.	8.4	10.4	12.6	14.6	16.8	18.8	21.	25.2	29.4	33.6	37.8	42.	47.	52.4	57.7	63.	73.4	84.	94.4
48 x 96	32.	9.6	11.9	14.4	16.7	19.2	21.5	24.	28.8	33.6	38.4	43.2	48.	53.8	59.9	65.9	72.	83.9	96.	107.8
50 x 108	37.5	11.3	13.9	16.9	19.5	22.5	25.1	28.2	33.8	39.3	45.	50.7	56.3	63.	70.1	77.3	84.4	98.3	112.5	126.4
52 x 84	30.4	9.1	11.3	13.7	15.8	18.3	20.4	22.8	27.4	31.9	36.5	41.	45.6	51.	56.9	62.6	68.4	79.6	91.2	102.5

Casks average about 600 pounds each. No. 4 to No. 17. Boxes average about 500 pounds. No. 18 and heavier.

UNITED STATES STANDARD GAUGE FOR SHEET AND PLATE IRON AND STEEL

COPY [Public—No. 137]

An act establishing a standard gauge for sheet and plate iron and steel.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That for the purpose of securing uniformity the following is established as the only standard gauge for sheet and plate iron and steel in the United States of America, namely:

Number of Gauge	THICKNESS		WEIGHT		Number of Gauge
	Approximate thickness in fractions of an inch	Approximate thickness in decimal parts of an inch	Weight per square foot in OUNCES avoirdupois	Weight per square foot in POUNDS avoirdupois	
0000000	1-2	.5	320	20.	0000000
000000	15-32	.46875	300	18.75	000000
00000	7-16	.4375	280	17.5	00000
0000	13-32	.40625	260	16.25	0000
000	3-8	.375	240	15.	000
00	11-32	.34375	220	13.75	00
0	5-16	.3125	200	12.5	0
1	9-32	.28125	180	11.25	1
2	17-64	.265625	170	10.625	2
3	1-4	.25	160	10.	3
4	15-64	.234375	150	9.375	4
5	7-32	.21875	140	8.75	5
6	13-64	.203125	130	8.125	6
7	3-16	.1875	120	7.5	7
8	11-64	.171875	110	6.875	8
9	5-32	.15625	100	6.25	9
10	9-64	.140625	90	5.625	10
11	1-8	.125	80	5.	11
12	7-64	.109375	70	4.375	12
13	3-32	.09375	60	3.75	13
14	5-64	.078125	50	3.125	14
15	9-128	.0703125	45	2.8125	15
16	1-16	.0625	40	2.5	16
17	9-160	.05625	36	2.25	17
18	1-20	.05	32	2.	18
19	7-160	.04375	28	1.75	19
20	3-80	.0375	24	1.5	20
21	11-320	.034375	22	1.375	21
22	1-32	.03125	20	1.25	22
23	9-320	.028125	18	1.125	23
24	1-40	.025	16	1.	24
25	7-320	.021875	14	.875	25
26	3-160	.01875	12	.75	26
27	11-640	.0171875	11	.6875	27
28	1-64	.015625	10	.625	28
29	9-640	.0140625	9	.5625	29
30	1-80	.0125	8	.5	30
31	7-640	.0109375	7	.4875	31
32	13-1280	.01015625	6½	.40625	32
33	3-320	.009375	6	.375	33
34	11-1280	.00859375	5½	.34375	34
35	5-640	.0078125	5	.3125	35
36	9-1280	.00703125	4½	.28125	36
37	17-2560	.0066406	4¼	.265625	37
38	1-160	.00625	4	.25	38

And on and after July first, eighteen hundred and ninety-three, the same and no other shall be used in determining duties and taxes levied by the United States of America on sheet and plate iron and steel. But this act shall not be construed to increase duties upon any articles which may be imported.

SEC. 2. That the Secretary of the Treasury is authorized and required to prepare suitable standards in accordance herewith.

SEC. 3. That in the practical use and application of the standard gauge hereby established a variation of two and one-half per cent either way may be allowed.

Approved, March 3, 1893.

WEIGHTS OF FLAT ROLLED IRON PER LINEAR FOOT.

Iron weighing 480 pounds per cubic foot.

Thickness in Inches.	1″	1¼″	1½″	1¾″	2″	2¼″	2½″	2¾″	12″
1/16	.208	.260	.313	.365	.417	.469	.521	.573	2.50
1/8	.417	.521	.625	.729	.833	.938	1.04	1.15	5.00
3/16	.625	.781	.938	1.09	1.25	1.41	1.56	1.72	7.50
1/4	.833	1.04	1.25	1.46	1.67	1.88	2.08	2.29	10.00
5/16	1.04	1.30	1.56	1.82	2.08	2.34	2.60	2.86	12.50
3/8	1.25	1.56	1.88	2.19	2.50	2.81	3.13	3.44	15.00
7/16	1.46	1.82	2.19	2.55	2.92	3.28	3.65	4.01	17.50
1/2	1.67	2.08	2.50	2.92	3.33	3.75	4.17	4.58	20.00
9/16	1.88	2.34	2.81	3.28	3.75	4.22	4.69	5.16	22.50
5/8	2.08	2.60	3.13	3.65	4.17	4.69	5.21	5.73	25.00
11/16	2.29	2.86	3.44	4.01	4.58	5.16	5.73	6.30	27.50
3/4	2.50	3.13	3.75	4.38	5.00	5.63	6.25	6.88	30.00
13/16	2.71	3.39	4.06	4.74	5.42	6.09	6.77	7.45	32.50
7/8	2.92	3.65	4.38	5.10	5.83	6.56	7.29	8.02	35.00
15/16	3.13	3.91	4.69	5.47	6.25	7.03	7.81	8.59	37.50
1	3.33	4.17	5.00	5.83	6.67	7.50	8.33	9.17	40.00
1 1/16	3.54	4.43	5.31	6.20	7.08	7.97	8.85	9.74	42.50
1 1/8	3.75	4.69	5.63	6.56	7.50	8.44	9.38	10.31	45.00
1 3/16	3.96	4.95	5.94	6.93	7.92	8.91	9.90	10.89	47.50
1 1/4	4.17	5.21	6.25	7.29	8.33	9.38	10.42	11.46	50.00
1 5/16	4.37	5.47	6.56	7.66	8.75	9.84	10.94	12.03	52.50
1 3/8	4.58	5.73	6.88	8.02	9.17	10.31	11.46	12.60	55.00
1 7/16	4.79	5.99	7.19	8.39	9.58	10.78	11.98	13.18	57.50
1 1/2	5.00	6.25	7.50	8.75	10.00	11.25	12.50	13.75	60.00
1 9/16	5.21	6.51	7.81	9.11	10.42	11.72	13.02	14.32	62.50
1 5/8	5.42	6.77	8.13	9.48	10.83	12.19	13.54	14.90	65.00
1 11/16	5.63	7.03	8.44	9.84	11.25	12.66	14.06	15.47	67.50
1 3/4	5.83	7.29	8.75	10.21	11.67	13.13	14.58	16.04	70.00
1 13/16	6.04	7.55	9.06	10.57	12.08	13.59	15.10	16.61	72.50
1 7/8	6.25	7.81	9.38	10.94	12.50	14.06	15.63	17.19	75.00
1 15/16	6.46	8.07	9.69	11.30	12.92	14.53	16.15	17.76	77.50
2	6.67	8.33	10.00	11.67	13.33	15.00	16.67	18.33	80.00

WEIGHTS OF FLAT ROLLED IRON PER LINEAR FOOT.

(Continued)

Thickness in Inches.	3″	3¼″	3½″	3¾″	4″	4¼″	4½″	4¾″	12″
1/16	.625	.677	.729	.781	.833	.885	.938	.990	2.50
1/8	1.25	1.35	1.46	1.56	1.67	1.77	1.88	1.98	5.00
3/16	1.88	2.03	2.19	2.34	2.50	2.66	2.81	2.97	7.50
1/4	2.50	2.71	2.92	3.13	3.33	3.54	3.75	3.96	10.00
5/16	3.13	3.39	3.65	3.91	4.17	4.43	4.69	4.95	12.50
3/8	3.75	4.06	4.38	4.69	5.00	5.31	5.63	5.94	15.00
7/16	4.38	4.74	5.10	5.47	5.83	6.20	6.56	6.93	17.50
1/2	5.00	5.42	5.83	6.25	6.67	7.08	7.50	7.92	20.00
9/16	5.63	6.09	6.56	7.03	7.50	7.97	8.44	8.91	22.50
5/8	6.25	6.77	7.29	7.81	8.33	8.85	9.38	9.90	25.00
11/16	6.88	7.45	8.02	8.59	9.17	9.74	10.31	10.89	27.50
3/4	7.50	8.13	8.75	9.38	10.00	10.63	11.25	11.88	30.00
13/16	8.13	8.80	9.48	10.16	10.83	11.51	12.19	12.86	32.50
7/8	8.75	9.48	10.21	10.94	11.67	12.40	13.13	13.85	35.00
15/16	9.38	10.16	10.94	11.72	12.50	13.28	14.06	14.84	37.50
1	10.00	10.83	11.67	12.50	13.33	14.17	15.00	15.83	40.00
1 1/16	10.63	11.51	12.40	13.28	14.17	15.05	15.94	16.82	42.50
1 1/8	11.25	12.19	13.13	14.06	15.00	15.94	16.88	17.81	45.00
1 3/16	11.88	12.86	13.85	14.84	15.83	16.82	17.81	18.80	47.50
1 1/4	12.50	13.54	14.58	15.63	16.67	17.71	18.75	19.79	50.00
1 5/16	13.13	14.22	15.31	16.41	17.50	18.59	19.69	20.78	52.50
1 3/8	13.75	14.90	16.04	17.19	18.33	19.48	20.63	21.77	55.00
1 7/16	14.38	15.57	16.77	17.97	19.17	20.36	21.56	22.76	57.50
1 1/2	15.00	16.25	17.50	18.75	20.00	21.25	22.50	23.75	60.00
1 9/16	15.63	16.93	18.23	19.53	20.83	22.14	23.44	24.74	62.50
1 5/8	16.25	17.60	18.96	20.31	21.67	23.02	24.38	25.73	65.00
1 11/16	16.88	18.28	19.69	21.09	22.50	23.91	25.31	26.72	67.50
1 3/4	17.50	18.96	20.42	21.88	23.33	24.79	26.25	27.71	70.00
1 13/16	18.13	19.64	21.15	22.66	24.17	25.68	27.19	28.70	72.50
1 7/8	18.75	20.31	21.88	23.44	25.00	26.56	28.13	29.69	75.00
1 15/16	19.38	20.99	22.60	24.22	25.83	27.45	29.06	30.68	77.50
2	20.00	21.67	23.33	25.00	26.67	28.33	30.00	31.67	80.00

WEIGHTS OF FLAT ROLLED IRON PER LINEAR FOOT.

(Continued)

Thickness in Inches.	5″	5¼″	5½″	5¾″	6″	6¼″	6½″	6¾″	12″
$\frac{1}{16}$	1.04	1.09	1.15	1.20	1.25	1.30	1.35	1.41	2.50
$\frac{1}{8}$	2.08	2.19	2.29	2.40	2.50	2.60	2.71	2.81	5.00
$\frac{3}{16}$	3.13	3.28	3.44	3.59	3.75	3.91	4.06	4.22	7.50
$\frac{1}{4}$	4.17	4.38	4.58	4.79	5.00	5.21	5.42	5.63	10.00
$\frac{5}{16}$	5.21	5.47	5.73	5.99	6.25	6.51	6.77	7.03	12.50
$\frac{3}{8}$	6.25	6.56	6.88	7.19	7.50	7.81	8.13	8.44	15.00
$\frac{7}{16}$	7.29	7.66	8.02	8.39	8.75	9.11	9.48	9.84	17.50
$\frac{1}{2}$	8.33	8.75	9.17	9.58	10.00	10.42	10.83	11.25	20.00
$\frac{9}{16}$	9.38	9.84	10.31	10.78	11.25	11.72	12.19	12.66	22.50
$\frac{5}{8}$	10.42	10.94	11.46	11.98	12.50	13.02	13.54	14.06	25.00
$\frac{11}{16}$	11.46	12.03	12.60	13.18	13.75	14.32	14.90	15.47	27.50
$\frac{3}{4}$	12.50	13.13	13.75	14.38	15.00	15.63	16.25	16.88	30.00
$\frac{13}{16}$	13.54	14.22	14.90	15.57	16.25	16.93	17.60	18.28	32.50
$\frac{7}{8}$	14.58	15.31	16.04	16.77	17.50	18.23	18.96	19.69	35.00
$\frac{15}{16}$	15.63	16.41	17.19	17.97	18.75	19.53	20.31	21.09	37.50
1	16.67	17.50	18.33	19.17	20.00	20.83	21.67	22.50	40.00
$1\frac{1}{16}$	17.71	18.59	19.48	20.36	21.25	22.14	23.02	23.91	42.50
$1\frac{1}{8}$	18.75	19.69	20.63	21.56	22.50	23.44	24.38	25.31	45.00
$1\frac{3}{16}$	19.79	20.78	21.77	22.76	23.75	24.74	25.73	26.72	47.50
$1\frac{1}{4}$	20.83	21.88	22.92	23.96	25.00	26.04	27.08	28.13	50.00
$1\frac{5}{16}$	21.88	22.97	24.06	25.16	26.25	27.34	28.44	29.53	52.50
$1\frac{3}{8}$	22.92	24.06	25.21	26.35	27.50	28.65	29.79	30.94	55.00
$1\frac{7}{16}$	23.96	25.16	26.35	27.55	28.75	29.95	31.15	32.34	57.50
$1\frac{1}{2}$	25.00	26.25	27.50	28.75	30.00	31.25	32.50	33.75	60.00
$1\frac{9}{16}$	26.04	27.34	28.65	29.95	31.25	32.55	33.85	35.16	62.50
$1\frac{5}{8}$	27.08	28.44	29.79	31.15	32.50	33.85	35.21	36.56	65.00
$1\frac{11}{16}$	28.13	29.53	30.94	32.34	33.75	35.16	36.56	37.97	67.50
$1\frac{3}{4}$	29.17	30.63	32.08	33.54	35.00	36.46	37.92	39.38	70.00
$1\frac{13}{16}$	30.21	31.72	33.23	34.74	36.25	37.76	39.27	40.78	72.50
$1\frac{7}{8}$	31.25	32.81	34.38	35.94	37.50	39.06	40.63	42.19	75.00
$1\frac{15}{16}$	32.29	33.91	35.52	37.14	38.75	40.36	41.98	43.59	77.50
2	33.33	35.00	36.67	38.33	40.00	41.67	43.33	45.00	80.00

WEIGHTS OF FLAT ROLLED IRON PER LINEAR FOOT.

(Continued)

Thickness in Inches.	7″	7¼″	7½″	7¾″	8″	8¼″	8½″	8¾″	12″
1/16	1.46	1.51	1.56	1.61	1.67	1.72	1.77	1.82	2.50
1/8	2.92	3.02	3.13	3.23	3.33	3.44	3.54	3.65	5.00
3/16	4.38	4.53	4.69	4.84	5.00	5.16	5.31	5.47	7.50
1/4	5.83	6.04	6.25	6.46	6.67	6.88	7.08	7.29	10.00
5/16	7.29	7.55	7.81	8.07	8.33	8.59	8.85	9.11	12.50
3/8	8.75	9.06	9.38	9.69	10.00	10.31	10.63	10.94	15.00
7/16	10.21	10.57	10.94	11.30	11.67	12.03	12.40	12.76	17.50
1/2	11.67	12.08	12.50	12.92	13.33	13.75	14.17	14.58	20.00
9/16	13.13	13.59	14.06	14.53	15.00	15.47	15.94	16.41	22.50
5/8	14.58	15.10	15.63	16.15	16.67	17.19	17.71	18.23	25.00
11/16	16.04	16.61	17.19	17.76	18.33	18.91	19.48	20.05	27.50
3/4	17.50	18.13	18.75	19.38	20.00	20.63	21.25	21.88	30.00
13/16	18.96	19.64	20.31	20.99	21.67	22.34	23.02	23.70	32.50
7/8	20.42	21.15	21.88	22.60	23.33	24.06	24.79	25.52	35.00
15/16	21.88	22.66	23.44	24.22	25.00	25.78	26.56	27.34	37.50
1	23.33	24.17	25.00	25.83	26.67	27.50	28.33	29.17	40.00
1 1/16	24.79	25.68	26.56	27.45	28.33	29.22	30.10	30.99	42.50
1 1/8	26.25	27.19	28.13	29.06	30.00	30.94	31.88	32.81	45.00
1 3/16	27.71	28.70	29.69	30.68	31.67	32.66	33.65	34.64	47.50
1 1/4	29.17	30.21	31.25	32.29	33.33	34.38	35.42	36.46	50.00
1 5/16	30.62	31.72	32.81	33.91	35.00	36.09	37.19	38.28	52.50
1 3/8	32.08	33.23	34.38	35.52	36.67	37.81	38.96	40.10	55.00
1 7/16	33.54	34.74	35.94	37.14	38.33	39.53	40.73	41.93	57.50
1 1/2	35.00	36.25	37.50	38.75	40.00	41.25	42.50	43.75	60.00
1 9/16	36.46	37.76	39.06	40.36	41.67	42.97	44.27	45.57	62.50
1 5/8	37.92	39.27	40.63	41.98	43.33	44.69	46.04	47.40	65.00
1 11/16	39.38	40.78	42.19	43.59	45.00	46.41	47.81	49.22	67.50
1 3/4	40.83	42.29	43.75	45.21	46.67	48.13	49.58	51.04	70.00
1 13/16	42.29	43.80	45.31	46.82	48.33	49.84	51.35	52.86	72.50
1 7/8	43.75	45.31	46.88	48.44	50.00	51.56	53.13	54.69	75.00
1 15/16	45.21	46.82	48.44	50.05	51.67	53.28	54.90	56.51	77.50
2	46.67	48.33	50.00	51.67	53.33	55.00	56.67	58.33	80.00

WEIGHTS OF FLAT ROLLED IRON PER LINEAR FOOT.

(Continued)

Thickness in Inches.	9″	9¼″	9½″	9¾″	10″	10¼″	10½″	10¾″	12″
1/16	1.88	1.93	1.98	2.03	2.08	2.14	2.19	2.24	2.50
1/8	3.75	3.85	3.96	4.06	4.17	4.27	4.38	4.48	5.00
3/16	5.63	5.78	5.94	6.09	6.25	6.41	6.56	6.72	7.50
1/4	7.50	7.71	7.92	8.13	8.33	8.54	8.75	8.96	10.00
5/16	9.38	9.64	9.90	10.16	10.42	10.68	10.94	11.20	12.50
3/8	11.25	11.56	11.88	12.19	12.50	12.81	13.13	13.44	15.00
7/16	13.13	13.49	13.85	14.22	14.58	14.95	15.31	15.68	17.50
1/2	15.00	15.42	15.83	16.25	16.67	17.08	17.50	17.92	20.00
9/16	16.88	17.34	17.81	18.28	18.75	19.22	19.69	20.16	22.50
5/8	18.75	19.27	19.79	20.31	20.83	21.35	21.88	22.40	25.00
11/16	20.63	21.20	21.77	22.34	22.92	23.49	24.06	24.64	27.50
3/4	22.50	23.13	23.75	24.38	25.00	25.62	26.25	26.88	30.00
13/16	24.38	25.05	25.73	26.41	27.08	27.76	28.44	29.11	32.50
7/8	26.25	26.98	27.71	28.44	29.17	29.90	30.63	31.35	35.00
15/16	28.13	28.91	29.69	30.47	31.25	32.03	32.81	33.59	37.50
1	30.00	30.83	31.67	32.50	33.33	34.17	35.00	35.83	40.00
1 1/16	31.88	32.76	33.65	34.53	35.42	36.30	37.19	38.07	42.50
1 1/8	33.75	34.69	35.63	36.56	37.50	38.44	39.38	40.31	45.00
1 3/16	35.63	36.61	37.60	38.59	39.58	40.57	41.56	42.55	47.50
1 1/4	37.50	38.54	39.58	40.63	41.67	42.71	43.75	44.79	50.00
1 5/16	39.38	40.47	41.56	42.66	43.75	44.84	45.94	47.03	52.50
1 3/8	41.25	42.40	43.54	44.69	45.83	46.98	48.13	49.27	55.00
1 7/16	43.13	44.32	45.52	46.72	47.92	49.11	50.31	51.51	57.50
1 1/2	45.00	46.25	47.50	48.75	50.00	51.25	52.50	53.75	60.00
1 9/16	46.88	48.18	49.48	50.78	52.08	53.39	54.69	55.99	62.50
1 5/8	48.75	50.10	51.46	52.81	54.17	55.52	56.88	58.23	65.00
1 11/16	50.63	52.03	53.44	54.84	56.25	57.66	59.06	60.47	67.50
1 3/4	52.50	53.96	55.42	56.88	58.33	59.79	61.25	62.71	70.00
1 13/16	54.38	55.89	57.40	58.91	60.42	61.93	63.44	64.95	72.50
1 7/8	56.25	57.81	59.38	60.94	62.50	64.06	65.63	67.19	75.00
1 15/16	58.13	59.74	61.35	62.97	64.58	66.20	67.81	69.43	77.50
2	60.00	61.67	63 33	65.00	66.67	68.33	70.00	71.67	80.00

WEIGHTS OF FLAT ROLLED IRON PER LINEAR FOOT.

(Concluded)

Thickness in Inches.	11″	11¼″	11½″	11¾″	12″	12¼″	12½″	12¾″
1/16	2.29	2.34	2.40	2.45	2.50	2.55	2.60	2.66
1/8	4.58	4.69	4.79	4.90	5.00	5.10	5.21	5.31
3/16	6.88	7.03	7.19	7.34	7.50	7.66	7.81	7.97
1/4	9.17	9.38	9.58	9.79	10.00	10.21	10.42	10.63
5/16	11.46	11.72	11.98	12.24	12.50	12.76	13.02	13.28
3/8	13.75	14.06	14.38	14.69	15.00	15.31	15.63	15.94
7/16	16.04	16.41	16.77	17.14	17.50	17.86	18.23	18.59
1/2	18.33	18.75	19.17	19.58	20.00	20.42	20.83	21.25
9/16	20.63	21.09	21.56	22.03	22.50	22.97	23.44	23.91
5/8	22.92	23.44	23.96	24.48	25.00	25.52	26.04	26.56
11/16	25.21	25.78	26.35	26.93	27.50	28.07	28.65	29.22
3/4	27.50	28.13	28.75	29.38	30.00	30.63	31.25	31.88
13/16	29.79	30.47	31.15	31.82	32.50	33.18	33.85	34.53
7/8	32.08	32.81	33.54	34.27	35.00	35.73	36.46	37.19
15/16	34.38	35.16	35.94	36.72	37.50	38.28	39.06	39.84
1	36.67	37.50	38.33	39.17	40.00	40.83	41.67	42.50
1 1/16	38.96	39.84	40.73	41.61	42.50	43.39	44.27	45.16
1 1/8	41.25	42.19	43.13	44.06	45.00	45.94	46.88	47.81
1 3/16	43.54	44.53	45.52	46.51	47.50	48.49	49.48	50.47
1 1/4	45.83	46.88	47.92	48.96	50.00	51.04	52.08	53.13
1 5/16	48.13	49.22	50.31	51.41	52.50	53.59	54.69	55.78
1 3/8	50.42	51.56	52.71	53.85	55.00	56.15	57.29	58.44
1 7/16	52.71	53.91	55.10	56.30	57.50	58.70	59.90	61.09
1 1/2	55.00	56.25	57.50	58.75	60.00	61.25	62.50	63.75
1 9/16	57.29	58.59	59.90	61.20	62.50	63.80	65.10	66.41
1 5/8	59.58	60.94	62.29	63.65	65.00	66.35	67.71	69.06
1 11/16	61.88	63.28	64.69	66.09	67.50	68.91	70.31	71.72
1 3/4	64.17	65.63	67.08	68.54	70.00	71.46	72.92	74.38
1 13/16	66.46	67.97	69.48	70.99	72.50	74.01	75.52	77.03
1 7/8	68.75	70.31	71.88	73.44	75.00	76.56	78.13	79.69
1 15/16	71.04	72.66	74.27	75.89	77.50	79.11	80.73	82.34
2	73.33	75.00	76.67	78.33	80.00	81.67	83.33	85.00

The weights for 12″ width are repeated on each page to facilitate making the additions necessary for plates wider than 12″. Thus, to find the weight of 15¾″ x ⅞″, add the weights to be found in the same line for 3¼″ x ⅞″ and 12″ x ⅞″ = 9.48 + 35.00 = 44.48 lbs.

SQUARE AND ROUND IRON BARS.

Thickness or Diameter in Inches.	Weight of □ Bar One Foot long.	Weight of ○ Bar One Foot long.	Area of □ Bar in sq. inches.	Area of ○ Bar in sq. inches.	Circumference of ○ Bar in inches.
0					
$\frac{1}{16}$	.013	.010	.0039	.0031	.1963
$\frac{1}{8}$	.052	.041	.0156	.0123	.3927
$\frac{3}{16}$	.117	.092	.0352	.0276	.5890
$\frac{1}{4}$	.208	.164	.0625	.0491	.7854
$\frac{5}{16}$	.326	.256	.0977	.0767	.9817
$\frac{3}{8}$	.469	.368	.1406	.1104	1.1781
$\frac{7}{16}$	.638	.501	.1914	.1503	1.3744
$\frac{1}{2}$	.833	.654	.2500	.1963	1.5708
$\frac{9}{16}$	1.055	.828	.3164	.2485	1.7671
$\frac{5}{8}$	1.302	1.023	.3906	.3068	1.9635
$\frac{11}{16}$	1.576	1.237	.4727	.3712	2.1598
$\frac{3}{4}$	1.875	1.473	.5625	.4418	2.3562
$\frac{13}{16}$	2.201	1.728	.6602	.5185	2.5525
$\frac{7}{8}$	2.552	2.004	.7656	.6013	2.7489
$\frac{15}{16}$	2.930	2.301	.8789	.6903	2.9452
1	3.333	2.618	1.0000	.7854	3.1416
$\frac{1}{16}$	3.763	2.955	1.1289	.8866	3.3379
$\frac{1}{8}$	4.219	3.313	1.2656	.9940	3.5343
$\frac{3}{16}$	4.701	3.692	1.4102	1.1075	3.7306
$\frac{1}{4}$	5.208	4.091	1.5625	1.2272	3.9270
$\frac{5}{16}$	5.742	4.510	1.7227	1.3530	4.1233
$\frac{3}{8}$	6.302	4.950	1.8906	1.4849	4.3197
$\frac{7}{16}$	6.888	5.410	2.0664	1.6230	4.5160
$\frac{1}{2}$	7.500	5.890	2.2500	1.7671	4.7124
$\frac{9}{16}$	8.138	6.392	2.4414	1.9175	4.9087
$\frac{5}{8}$	8.802	6.913	2.6406	2.0739	5.1051
$\frac{11}{16}$	9,492	7.455	2.8477	2.2365	5.3014
$\frac{3}{4}$	10.21	8.018	3.0625	2.4053	5.4978
$\frac{13}{16}$	10.95	8.601	3.2852	2.5802	5.6941
$\frac{7}{8}$	11.72	9.204	3.5156	2.7612	5.8905
$\frac{15}{16}$	12.51	9.828	3.7539	2.9483	6.0868
2	13.33	10.47	4.0000	3.1416	6.2832
$\frac{1}{16}$	14.18	11.14	4.2539	3.3410	6.4795
$\frac{1}{8}$	15.05	11.82	4.5156	3.5466	6.6759
$\frac{3}{16}$	15.95	12.53	4.7852	3.7583	6.8722
$\frac{1}{4}$	16.88	13.25	5.0625	3.9761	7.0686
$\frac{5}{16}$	17.83	14.00	5.3477	4.2000	7.2649
$\frac{3}{8}$	18.80	14.77	5.6406	4.4301	7.4613
$\frac{7}{16}$	19.80	15.55	5.9414	4.6664	7.6576
$\frac{1}{2}$	20.83	16.36	6.2500	4.9087	7.8540
$\frac{9}{16}$	21.89	17.19	6.5664	5.1572	8.0503
$\frac{5}{8}$	22.97	18.04	6.8906	5.4119	8.2467
$\frac{11}{16}$	24.06	18.91	7.2227	5.6727	8.4430

SQUARE AND ROUND IRON BARS.

(Concluded)

Thickness or Diameter in Inches.	Weight of ☐ Bar One Foot long.	Weight of ○ Bar One Foot long.	Area of ☐ Bar in sq. inches.	Area of ○ Bar in sq. inches.	Circumference of ○ Bar in inches.
¾	25.21	19.80	7.5625	5.9396	8.6394
13/16	26.37	20.71	7.9102	6.2126	8.8357
⅞	27.55	21.64	8.2656	6.4918	9.0321
15/16	28.76	22.59	8.6289	6.7771	9.2284
3	30.00	23.56	9.0000	7.0686	9.4248
1/16	31.26	24.55	9.3789	7.3662	9.6211
⅛	32.55	25.57	9.7656	7.6699	9.8175
3/16	33.87	26.60	10.160	7.9798	10.014
¼	35.21	27.65	10.563	8.2958	10.210
5/16	36.58	28.73	10.973	8.6179	10.407
⅜	37.97	29.82	11.391	8.9462	10.603
7/16	39.39	30.94	11.816	9.2806	10.799
½	40.83	32.07	12.250	9.6211	10.996
9/16	42.30	33.23	12.691	9.9678	11.192
⅝	43.80	34.40	13.141	10.321	11.388
11/16	45.33	35.60	13.598	10.680	11.585
¾	46.88	36.82	14.063	11.045	11.781
13/16	48.45	38.05	14.535	11.416	11.977
⅞	50.05	39.31	15.016	11.793	12.174
15/16	51.68	40.59	15.504	12.177	12.370
4	53.33	41.89	16.000	12.566	12.566
1/16	55.01	43.21	16.504	12.962	12.763
⅛	56.72	44.55	17.016	13.364	12.959
3/16	58.45	45.91	17.535	13.772	13.155
¼	60.21	47.29	18.063	14.186	13.352
5/16	61.99	48.69	18.598	14.607	13.548
⅜	63.80	50.11	19.141	15.033	13.744
7/16	65.64	51.55	19.691	15.466	13.941
½	67.50	53.01	20.250	15.904	14.137
9/16	69.39	54.50	20.816	16.349	14.334
⅝	71.30	56.00	21.391	16.800	14.530
11/16	73.24	57.52	21.973	17.257	14.726
¾	75.21	59.07	22.563	17.721	14.923
13/16	77.20	60.63	23.160	18.190	15.119
⅞	79.22	62.22	23.766	18.665	15.315
15/16	81.26	63.82	24.379	19.147	15.512
5	83.33	65.45	25.000	19.635	15.708

ANGLE IRON.

Weight Per Linear Foot.

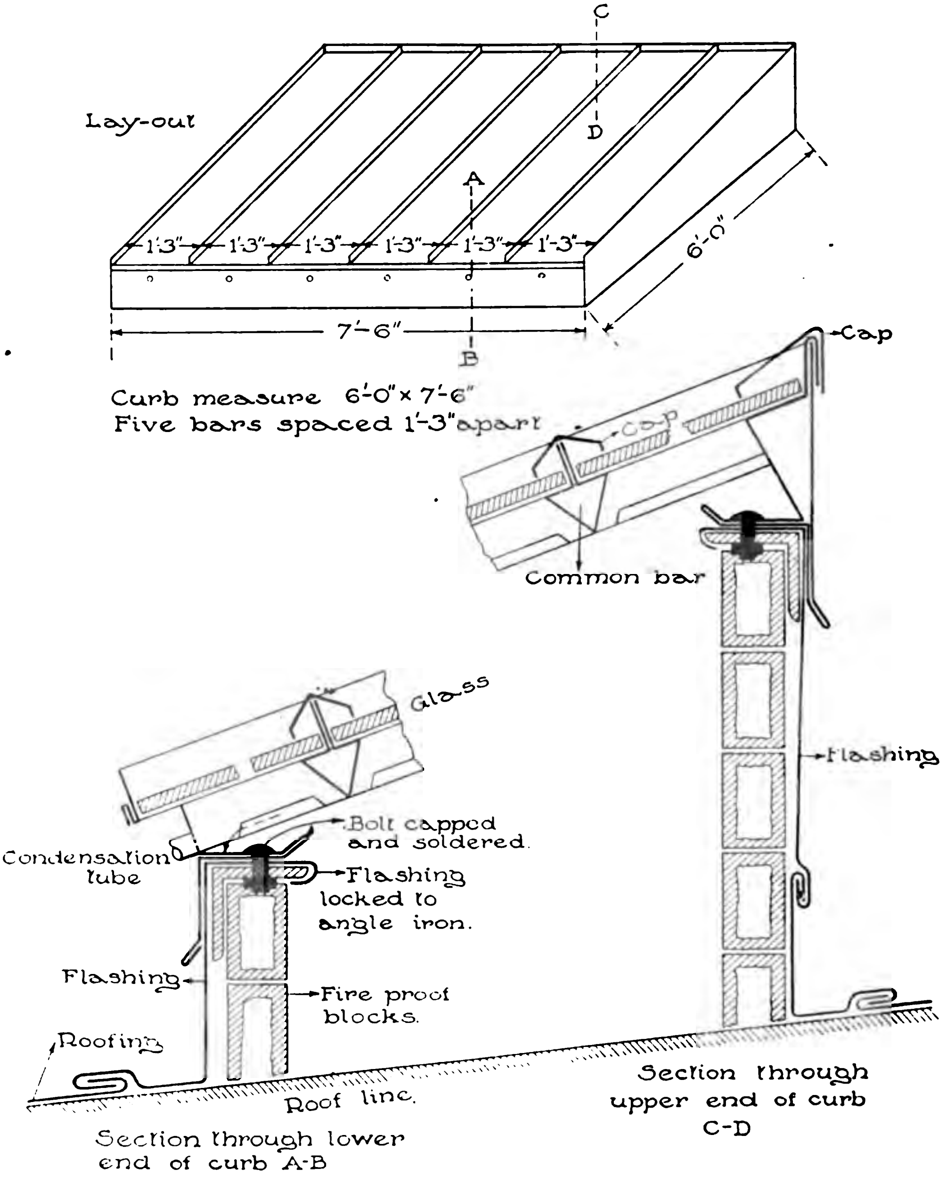
6 x 6 x ⅝	24	Lbs.	2 x 2 x ¼	3½	Lbs.
5 x 5 x 9/16	16½	“	1¾ x 1¾ x 3/16	2¾	“
4 x 4 x ½	12½	“	1½ x 1½ x 3/16	2	‘
3½ x 3½ x 7/16	9	“	1¼ x 1¼ x 3/16	1½	“
3 x 3 x ⅜	7	“	1 x 1 x ⅛	1	“
2½ x 2½ x 5/16	5	“	¾ x ¾ x ⅛	⅝	“
2¼ x 2¼ x ¼	4¼	“			

TEE IRON.

Weight Per Linear Foot.

5 x 8 x ⅝	30	Lbs.	2¼ x 2¼ x ¼	4	Lbs
7 x 6 x ⅝	30	“	2 x 2 x ¼	3¼	“
6 x 3 x ½	16½	“	1¾ x 1¾ x ¼	3	“
4 x 4 x ½	14	“	1½ x 1½ x ¼	2¾	“
3½ x 3½ x ½	12½	“	1¼ x 1¼ x ¼	2¼	“
3 x 3 x ⅜	7¾	“	1 x 1 x ⅛	1	“
2½ x 2½ x ½	8	“	¾ x ¾ x ⅛	⅜	“
2½ x 2½ x 5/16	5	“			

CONSTRUCTION DRAWING SHOWING LAYOUT OF FLAT SKYLIGHT AND METHOD OF FASTENING FLASHING ON ANGLE IRON CONSTRUCTION.



Curb measure 6'-0" × 7'-6"
Five bars spaced 1'-3" apart

Section through lower end of curb A-B

Section through upper end of curb C-D

PRACTICAL PROBLEMS IN MENSURATION FOR SHEET METAL WORKERS.

A square tank, Fig. 1, is required whose capacity should be 200 gallons, the sides *b a* and *a c* each to be 30 inches; how high must *c d* be, so that the tank will hold the desired quantity?

Suppose the height *c d* is to be $51\frac{1}{3}$ inches, and the tank is to have similar capacity, and one side *c a* is to be 20 inches wide, how long must the alternate side *a b* be, so that the tank will hold 200 gallons?

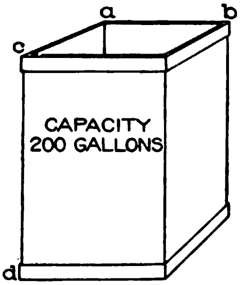


Fig. 1.

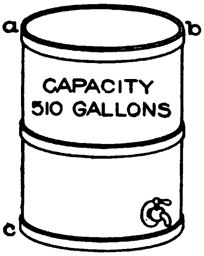


Fig. 2.

A round tank, Fig. 2, is to be constructed whose capacity should equal 510 gallons, and be 5 feet high from *c* to *a*; what must its diameter *a b* be, so as to hold the desired capacity?

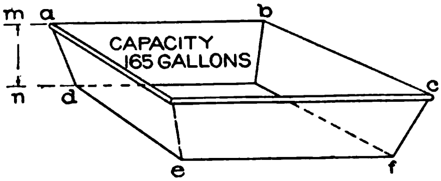


Fig. 3.

Suppose the diameter of the tank is to be 50 inches as *a b*; what must its height *a c* be, so that the tank will hold 510 gallons?

A large drip pan, Fig. 3, is to be constructed whose capacity should be 165 gallons, and whose top measurements *a b* and *b c* are 60 × 40 inches respectively, and bottom measurements *d e* and *e f* 34 × 54 inches respectively; what must its height *m n* be, so as to hold the desired volume ?

A round tapering measure, Fig. 4, is to be constructed whose volume will equal 42 quarts; its bottom diameter *a b* is to be 14 inches, its top diameter *c d* 18 inches; what must its height *e f* be to hold the desired quantity ?

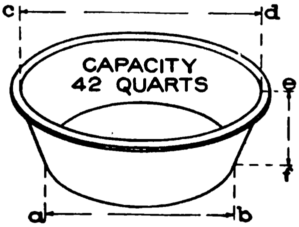


Fig. 4.

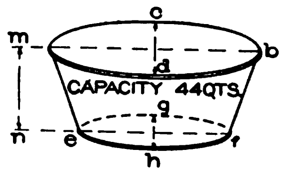


Fig. 5.

An elliptical tapering tank, Fig. 5, is to be constructed whose major axis *m b* is 24 inches, and minor axis *c d* 14 inches at the top, while at the bottom the major axis *e f* is 20 inches, and minor axis *g h* 10 inches; the capacity of the tank should equal 44 quarts; what must the height *m n* be, so that the tank will hold the desired amount ?

A tank, Fig. 6, is to be constructed with semicircular ends whose capacity should equal 30 gallons; the length *a b* to be 20 inches, and the diameters of *c* and *d* to be each 10 inches; what must the height *e f* be, so that the tank will hold the desired quantity ?

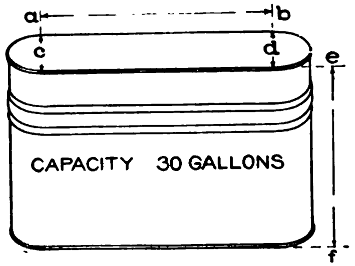


Fig. 6.

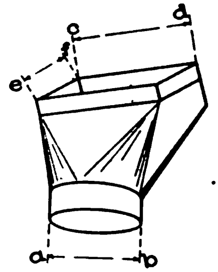


Fig. 7.

Suppose the height *e f* is to be 24 inches, the diameters *c* and *d* each 11 inches; what must the length of *a b* be, so that the tank will hold 30 gallons ?

In Fig. 7 is shown a fitting used in ventilation piping; the diameter *a b* is $11\frac{1}{4}$ inches and it is desired that the oblong pipe on the opposite end shall have an area similar to the round pipe *a b*; if *e f* must be 5 inches, what must *c d* be so that both areas are alike?

Suppose the pipe is to be square in place of oblong, what must the length of each side be, so that both ends have similar area?

In Fig. 8, *a b* is 40 inches in diameter; and each one of the branches *c*, *d*, and *e* are to have equal diameters, what must the diameter of the branches be, so that the combined area of *c*, *d*, and *e* will equal the area of *a b*?

If *c* is 10 inches in diameter, *d* 12 inches, and *e* 8 inches, what must be the diameter of *a b*, to have the combined area of the branches?

Fig. 9 shows a transition piece from a round pipe *a* to an elliptical pipe *b*, both sections to have similar area; if the round pipe is 24 inches in diameter, and the major axis of the elliptical pipe must be 32 inches, what must the minor axis of *b* be so that the area at *b* will equal the area of *a*?

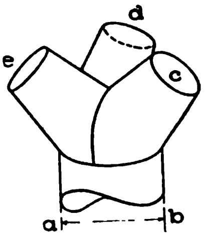


Fig. 8.

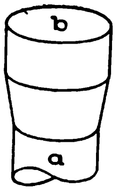


Fig. 9.

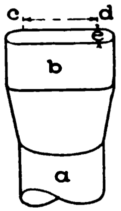


Fig. 10.

If the minor axis of *b* is to be 16 inches and the major axis 35 inches, what must the diameter of *a* be, so that both sections will have similar area?

In Fig. 10, *a* is 20 inches in diameter and forms a transition to an oblong pipe with semicircular end; the semicircular ends are to be 10 inches in diameter; what must the length of *c d* be, so that the area of *b* will be equal to the area of *a*?

If the pipe *b* measured 40 × 11 inches, having semicircular ends, what must the diameter of *a* be, so that both sections are equal in area?

If *a* is 20 inches in diameter and the upper section was to be rectangular in shape, 8 inches wide, what would the length of the upper section be?

Suppose the upper section *b* was desired to be square, what must the length of each side be, to have an area similar to *a*?

In Fig. 11 is shown the illustration of an ordinary steel square, and the method is given of obtaining accurate diameters of pipes, round or square, without any computation whatever, the rule being based on the geometrical principle that the square of the hypothenuse of a right angle triangle is equal to the sum of the squares of its base and altitude. To illustrate the rule, Fig. 12 has been

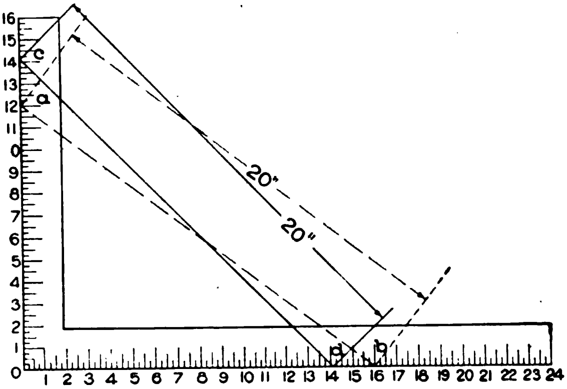


Fig. 11.

prepared. Let A represent a round or square pipe, 20 inches across, and B a round or square pipe 12 inches across; it is desired to take a branch from the main so that the two branches B and C will equal the area of the main A. What must the size of C be?

The size of C is found by simply taking a rule 20 inches long and placing one end on the arm of the square in Fig. 11, on the number 12, when the opposite end of the rule will touch the number 16. Then 16 is the required size of the branch C in Fig. 12. We can prove this by computation which, however, is not necessary in practice. The area of a 20-inch round pipe equals 314.16 in.; area of 12-in. pipe = 113.098 in.; area of 16-in. pipe = 201.062 in.; and 113.098 in. + 201.062 in. = 314.160 in. The area of a 20-in. square pipe = 400 in.; area of 12-in. square pipe = 144 in.; area of 16-in. square pipe = 256 in.; and 256 in. + 144 in. = 400 in.

Suppose any two branches are given as B and C in Fig. 12, what must the size of A be so that its area will have the combined area of the two branches?

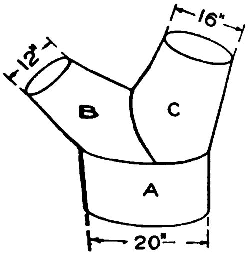


Fig. 12.

Simply set the rule on the numbers 12 and 16 on the two arms of the square respectively, and the length from *a* to *b* in Fig. 11 will measure 20 inches.

If A, Fig. 12, were given, and two branches were required, so that B and C were both of equal size, then simply set the rule 20 inches long, on both arms of the square so that the distance from O to *c* and O to *d* would be equal, as shown in Fig. 11, which would be found to measure $14\frac{1}{7}$ in. plus a least trifle. This rule can be used to advantage for any size round or square pipe in blower, blast, heat, and ventilating piping, saving time and trouble in computation. Where no square is at hand, one can be drawn on paper and used for work of this kind.

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for College, Civil Service, or Engineer's License. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

GAS-PRODUCERS.

1. How may gases be classified? Define each. To which class does producer gas belong?

2. Into how many classes may the constituents of producer gas be divided? Name each.

3. What effect have the different constituents of producer gas on its properties?

4. What is a fixed gas?

5. Why are gas analyses referred to a standard condition?

6. Explain what is meant by the sensible heat of a gas.

7. Explain the different methods of gas firing.

8. Explain the difference between retort and coke oven gas.

9. What are the essential elements of a successful fuel gas process?

10. Why has producer gas been able to defeat its competitors?

11. How was the producer-gas process first suggested?

12. When was the first gas-producer built?

13. When was producer gas first used for power purposes?

14. What is simple producer gas? Why is its use obsolete?

15. Why may the producer-gas process be spoken of as a triplex process?

16. What is a steam blower? Why should the solid-jet type not be used?

17. Into how many steps may the chemical action in the gas-producer be divided? Name and explain each in detail.

18. What is the object of the ash-zone?

19. Why should the exit temperature of the gas be low?

20. Discuss the value of preheated air.

21. Why is the temperature of the fire important?

22. Explain how the steam acts as a carrier of heat energy between the producer and combustion chamber.

23. How much steam should be given to the producer?

24. What fuels can be used in gas-producers?

25. What effect has the fuel on the resulting gas?

26. What is the advantage of crushed coal?

27. Name some of the absurd terms that have been used.

28. Distinguish between a pressure and an induced-draft producer.

29. Define a suction gas-producer.

30. Why is the efficiency of a gas-producer always less than unity?

31. What should be the efficiency of a good gas-producer?

32. Name the two forms of heat in the gas.

33. Define grate efficiency.

34. Of what value is the testing of a gas-producer?

35. How many heat losses in a gas-producer? Name the important ones.

36. Describe the heat balance.

37. What is the value of the heat balance?

38. Into how many groups may all gas-producers be divided?

39. Explain the difference between an induced-draft and a suction gas-producer.

40. Why is the accurate regulation of the water or steam going to suction gas-producers so desirable?

REVIEW QUESTIONS

ON THE SUBJECT OF

GAS AND OIL ENGINES.

1. Describe the cycle of operations in the Lenoir engine.

2. What is the usual pressure in the cylinder when the exhaust valve opens? What device is used to reduce the work necessary to raise a valve against that pressure?

3. What is an internal combustion motor, and what are its principal advantages over the external combustion motor?

4. Describe a gas producer plant and explain the differences between the pressure and the suction types of producer plant. Will a given gas engine develop as much power with producer gas as with coal gas?

5. What is the pressure at the end of compression in the ideal Otto cycle engine with 30% clearance?

6. What is the efficiency of the engine in the previous problem, and what is the probable efficiency of an actual engine with the same clearance?

7. What is an external combustion motor and what are its principal defects?

8. Describe the series of operations of the Otto cycle.

9. Explain the hit-and-miss system of governing gas engines. How is it carried out? What are its disadvantages?

10. What are the functions of the valves used in a gas engine? What kind of valve is generally used? Which of the valves may be automatic in action?

11. Draw and explain the indicator card of an engine using the Otto cycle with increased expansion.

12. Describe the procedure in starting a small gas engine by hand. How can a large gas engine be started?

13. What is the usual method of actuating the valves? What must be the speed of revolution of the side shaft?

14. Why is it possible (a) to compress to higher pressures, and (b) to use a larger excess of air with the Diesel cycle than with the Otto cycle? How is the governing carried out in the Diesel engine?

15. Describe the method of burning heavy oils used in the Hornsby-Akroyd engine.

16. Describe the procedure in starting an engine with gasoline. How much gasoline does an average engine use per brake horse power per hour?

17. What are the most common causes of failure to start in a gas engine? How would you set to work to find out the trouble?

18. How may kerosene be vaporized before being sent to the cylinder of the engine? What is meant by the cracking of kerosene, and how is it caused?

19. What is carbureted air? Describe the action of a carburetor for gasoline. Where should the gasoline tank be placed?

20. Draw the indicator card for the Otto cycle. What kind of compression occurs in this cycle?

21. What is back-firing, how is it caused and how remedied?

22. What is the average fuel consumption in a gas engine?

23. What are the fuels used in oil engines? How are they obtained and how may they be distinguished from one another?

24. Upon what does the efficiency of the Otto cycle depend? Under what conditions will the efficiency be high?

25. Describe hot tube ignition.

26. Explain the operation of a make-and-break igniter. Sketch the necessary electric connections.

27. Explain carefully the series of operations in a two-cycle gas engine. What are the advantages and defects of this type?

28. Describe the Diesel cycle and draw an indicator card illustrating the processes.

29. Describe three methods of governing by the variable-impulse system and discuss their relative advantages.

30. What do you understand by timing the ignition, and by lead of the ignition? What is the effect of too small lead and what of too great lead? Illustrate by indicator cards.

REVIEW QUESTIONS

ON THE SUBJECT OF

AUTOMOBILES

1. What is the function of mufflers, and what troubles are they liable to develop?

2. Describe the methods of cylinder cooling in general use. What is the most economical temperature for the cylinders of a gasolene motor?

3. Describe the sliding gear transmission.

4. What is the difference in the action of the block, roller, and self-adjusting sprocket chains?

5 If the brake refuses to act what alternative remains to stop the machine?

6. How is the flexibility of the propeller shaft secured?

7. What forms of cooling surfaces are commonly used for air-cooled cylinders?

8. Describe the three forms of ignition.

9. Describe the steps to be taken in the operation of an automobile, and state what parts of the machine require special attention.

10. Name the three general classes of automobiles.

11. Explain the difference between 2-cycle and 4-cycle motors.

12 Describe the multiple disc clutch.

13. What is the effect on the motor of too rich gas?

14. Describe the usual method of steering an automobile.

15. How is the circulation of air maintained for air-cooling?

16. How is a sprag used?

17. Describe the white steam generator. How does it differ from an ordinary boiler?

18. What is the relative position of the clutch in the transmission system?

19. What causes premature ignition, and what is its effect?

20. What are the most common chain troubles, and how are they remedied?

21. Describe the devices used to supplement the springs of automobiles.

22. Describe four forms of friction drives.

23. What changes in automobile design are suggested by American road conditions?

24. What are the essential features of the rear axle?

25. What operations may be controlled by the steering wheel?

26. What kinds of bearings are in general use? Give the relative advantages of each kind.

27. How can the compression be tested?

28. Describe the methods used for varying the proportion of gasolene and air in different carburettors.

29. Describe the types of pumps used for water circulation.

30. Describe each of the essential parts of a gasolene motor.

31. What is the object of the differential gear, and where is it used?

32. What type of wheel is commonly used for automobiles? Describe its construction.

33. What considerations determine the location of the engine on the chassis?

34. What is the function of planetary gears, and how do they operate?

35. What is the function of radius rods, and where should they be located?

36. What is the most common form of brake for automobiles?

37. What is the most desirable method of vehicle control?

38. What is the general arrangement of the propeller shaft transmission?

39. What are the three methods of fastening pneumatic tires tc the wheel rims?

REVIEW QUESTIONS

ON THE SUBJECT OF

ELEVATORS.

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1. How does the plunger elevator operate?

2. How is the speed of a water-balance elevator controlled?

3. What is an electric limit switch?

4. What arrangement of packing is used for the pistons of hydraulic elevators?

5. How are air cushions arranged?

6. Describe the distributing valve used on the early steam elevators.

7. What kind of safeties are used with steel guides?

8. Describe the best form of limit valve for hydraulic elevators.

9. Describe the two earliest types of steam winding engines.

10. What is the function of a pilot valve?

11. What precaution should be taken with elevator cables?

12. What kind of cylinder lubrication is best for hydraulic cylinders?

13. Name three kinds of hydraulic elevators.

14. What safety device was used in connection with the spur-gear winding engine?

15. How is the Fraser elevator operated?

16. Explain the method of counter-weighting the cage and cables.

17. How is a pressure tank used?

18. Describe the method of mechanical control for electric elevators.

19. When two counterbalance weights are used, how should they be arranged?

20. How does a water-balance elevator operate?

21. Describe the arrangement of safety governors and dogs.

22. What is the advantage of the vertical over the horizontal hydraulic elevator?

23. How is the speed of electric elevators controlled?

24. What is the usual form of counterbalance weights?

25. Describe the action of a two-way operating valve.

26. Describe the method of electrical control for high-speed elevators.

27. Describe the automatic stop used with the spur-gear winding engine.

28. Make a sketch showing general arrangement of the horizontal hydraulic elevator.

29. What wood is used for guide-ways?

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